The effect of dietary energy content and the provision of a β-adrenergic agonist in the diet, on the production and meat quality of South African Mutton Merino feedlot lambs

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Thesis presented in fulfilment of the requirements for the degree of
MASTER OF SCIENCE IN AGRICULTURE
(ANIMAL SCIENCES) *in the Faculty of AgricSciences*
at Stellenbosch University

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Date: April 2014

Declaration

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Summary

Two studies were conducted on Elsenburg Experimental Farm, Western Cape, South Africa. The aim of these trials was to determine the following:

1) the effect of dietary energy as well as the inclusion of a β-adrenergic agonist (β-AA) on the production of South African Mutton Merino (SAMM) feedlot lambs

2) the effect of the trial diets on the rumen pH

3) the effect of varying dietary energy levels and the inclusion of a β-AA in the diet on the relationship between slaughter weight, commercial cut yield and bone:fat:muscle ratio of SAMM feedlot lambs

4) the effect of dietary energy as well as the inclusion/absence of a β-AA on the meat quality of SAMM feedlot lambs

5) the effect of dietary energy as well as the inclusion/absence of a β-AA on the sensory, physical and chemical characteristics of SAMM feedlot lambs.

To quantify the effects of these parameters the study was conducted in two separate experiments. In the first experiment one hundred and eight (108) SAMM lambs, weaned at *ca* 120 days of age of different gender (rams and ewes) were housed in individual pens for approximately 6 weeks. The treatments consisted of three different dietary energy level diets (high – 12.7 ME MJ/kg, medium – 12.0 ME MJ/kg and low 11.3 ME ME/kg) with either the inclusion or absence of a β-AA (Zilpaterol hydrochloride, at 8.6 g/ton) in the diet. The experiment was arranged as a 2 x 2 x 3 factorial design with gender (rams or ewes), β-AA (provided or not) and dietary energy level (low, medium or high) as main factors. In the second experiment one hundred and twenty (120) SAMM lambs, weaned at *ca* 120 days of age of different gender (wethers or ewes) were housed in individual pens for approximately 6 weeks. The treatments consisted of three different dietary energy level diets (low – 11.3 ME MJ/kg, medium – 12.0 ME MJ/kg and high – 12.7 ME MJ/kg). The experiment was arranged as a 2 x 3 factorial design with gender (wethers or ewes) and dietary energy level (high, medium or low) as main factors. Where no interaction occurred the data is presented as the effect of dietary energy level, β-AA and gender on parameters.

Three ruminally cannulated sheep were used for measuring the rumen pH. No differences were found between the three experimental diets on the rumen pH. Overall a gradual decline in pH from the time the animals were fed was observed. Dietary energy level only affected

the dressing percentage in the first experiment, while it affected several parameters in the second experiment. The β-AA had no significant (P>0.05) effect on any parameters. While gender significantly (P<0.05) effect several of the production and carcass yield parameters.

Main effects dietary energy and gender affected the leg yield and fat percentage in the bone:muscle:fat relationship respectively. While positive correlations between slaughter weight and the following parameters were observed: carcass weight, leg yield, shoulder yield, neck yield, flank yield and cranial fat thickness.

Beta-adrenergic agonists are commonly used in livestock production to enhance meat production and decrease the fat content of the body. Beta-adrenergic agonists normally improve growth performance and enhance a leaner carcass. The factors β-AA and dietary energy level had no effect on the proximate composition of the loin, fat thickness or the tenderness of the meat. The ewes had a significant higher fat content than the ram lambs. The meat of the ram lambs was less tender than the meat from the ewe lambs.

The acceptability of meat is dependent on the toughness (chewiness and resistance), flavour (aroma and taste) and succulence (juiciness) of the meat. It is known that dietary energy as well as the inclusion of a β-adrenergic agonist may influence the sensory, physical and chemical characteristics of the meat. No significant differences (P>0.05) due to dietary energy level or the inclusion of the β-AA were found for the physical characteristics of the meat. There were, however significant (P<0.05) differences found during the sensory testing for tenderness between gender (76.2% for ewes vs 72.9% for rams) and between the β-agonist groups (75.4% vs 72.9% for the inclusion of the β-AA). Sustained juiciness was also affected (P<0.05) by gender (68.0% for ewes vs 65.7% for rams) and the inclusion of a β-agonist groups (67.9% absent vs 65.8% included). Overall it was concluded that, of all three main effects, gender had affected the meat attributes the most.

Opsomming

Twee afsonderlike proewe is uitgevoer op Elsenburg Proefplaas, Wes-Kaap, Suid-Afrika. Die doel van die proewe was om die volgende te bepaal:

1) die effek van verskillende dieet-energievlakke tesame met die teenwoordigheid/afwesigheid van `n Beta-adrenergiese agonis (β-AA) op die produksie van Suid-Afrikaanse Vleismerino (SAVM) voerkraallammers;
2) die effek van die proefdiëte op die rumen pH;
3) die effek van verskillende dieet-energievlakke met die teenwoordigheid/afwesigheid van `n β-AA op die verhouding tussen slagmassa en die opbrengs van kommersiële vleissnitte sowel as op die van been:spier:vet-verhouding van SAVM voerkraallammers;
4) die effek van dieet-energie met die teenwoordigheid/afwesigheid van `n β-AA op die vleis kwaliteit van SAVM voerkraallammers;
5) die effek van dieet-energie sowel as die teenwoordigheid/afwesigheid van `n β-AA op die sensoriese, fisiese en chemiese eienskappe van SAVM voerkraallammers.

Twee afsonderlike proewe is uitgevoer om die effek van die parameters te kwantifiseer. Een honderd en agt (108) SAVM lammers is tydens die eerste eksperiment gebruik, hierdie lammers het bestaan uit beide ooie en ramme. Die lammers is gespeen op `n ouderdom van ongeveer 120 dae, en gehuisves in individuele hokkies vir `n tydperk van ongeveer 6 weke. Die proef het uit 6 behandelings bestaan: `n lae (11.3 ME MJ/kg), medium (12.0 ME MJ/kg) en `n hoë (12.7 ME MJ/kg) dieet-energievlakke, met of sonder `n β-AA (ingesluit teen 8.6 g/ton). Die eksperiment was `n 3 (dieet-energievlakke) x 2 (β-AA) x 2 (geslag) faktoriaal ontwerp. Een honderd en twintig (120) SAVM lammers is tydens die tweede eksperiment gebruik, hierdie lammers het bestaan uit beide hammels en ooie.. Die lammers is gespeen op `n ouderdom van ongeveer 120 dae, en gehuisves in individuele hokkies vir `n tydperk van ongeveer 6 weke. Die proef het uit 3 behandelings bestaan: `n lae (11.3 ME MJ/kg), medium (12.0 ME MJ/kg) en `n hoë (12.07 ME MJ/kg) dieet-energievlak. Die eksperiment was `n 3 (dieet-energievlakke) x 2 (geslag) faktoriaal ontwerp. Die data word aangebied as die effek van dieet-energievlakke, β-AA en geslag op die verskeie parameters. Waar daar egter interaksies waargeneem was, is die data aangebied as die effek van die interaksies op gemete parameters.

Drie fistel skape was gebruik tydens die meet van die rumen pH. Geen betekenisvolle verskille is gevind tussen die drie proef diëte op die pH van die rumen nie. Op `n geheel oorsig is daar `n geleidelike afname in pH waargeneem, vandat die diere gevoer was. Dieet-energievlakke het slegs die uitslag persentasie in die eerste proef beïnvloed, terwyl dit `n verskeidenheid parameters in die tweede proef beïnvloed het. Die β-AA het geen betekenisvolle verskil ($P>0.05$) op enige parameter gehad nie. Terwyl geslag `n verskeidenheid produksie en karkas opbrengs parameters betekenisvol ($P>0.05$) beïnvloed het.

Die hoof effekte, dieet-energievlakke en geslag, het beide die boud opbrengs en die vet persentasie in die been:spier:vet verhouding afsonderlik beïnvloed. Positiewe korrelasies is waargeneem tussen slagmassa en die volgende parameters: karkas gewig, boud opbrengs, skouer opbrengs, nek opbrengs, rib/lies opbrengs en die kraniale vet dikte.

Beta-agoniste word algemeen gebruik in die voere van vee, om die vleis produksie te verbeter en terselfdertyd die vet inhoud van die karkas te verlaag. Die hoof effekte, β-AA en dieet-energievlak, het geen effek op die proksimale samestelling, vet dikte of die sagtheid van die vleis gehad nie. Die ooie het `n betekenisvolle hoër vet inhoud gehad as dié van ram lammers, terwyl die vleis van die ram lammers weer taaier was as dié van ooi lammers.

Die aanvaarbaarheid van vleis is afhanklik van die taaiheid, geur, smaak en sappigheid. Die sensoriese, fisiese en chemiese eienskappe van vleis word deur beide dieet-energievlakke en die teenwoordigheid/afwesigheid van `n β-AA beïnvloed. Beide die dieet-energievlak en die teenwoordigheid van die β-AA het geen betekenisvolle ($P>0.05$) verskille gehad op die fisiese eienskappe van die vleis nie. Daar was wel betekenisvolle verskille ($P<0.05$) gevind tydens die sensoriese toetse op die vleis. Die vleis van die ramme (76.2% vs 72.9%) teenoor dié van die ooie, sowel as die vleis van die lammers wat die β-AA ontvang (75.45% vs 72.9%) het teenoor dié lammers wat nie die β-AA ontvang het nie, was taaier.

Acknowledgements

I would like to express my gratitude and appreciation to the following institutions and people that made the successfully completion of this thesis possible:

Prof L.C. Hoffman, Department of Animal Sciences, Stellenbosch University (US) and **Prof T.S. Brand**, The Directorate: Animal Science at Elsenburg, who comprised the study committee, for their patience, guidance and support.

Personnel of the Animal Production Division at **Elsenburg** and **Kromme Rhee**, especially **Mr C. van der Walt** and his workers and **Ms R. Swart** for their assistance, in lab work and the feeding and care of the lambs during the study.

Malmesbury, Roelcor Abattoir for friendly co-operation and for providing slaughter facilities and the staff that assisted with the slaughter process.

Ms G. Jordaan Department of Animal Sciences, University of Stellenbosch (US) for her friendly, assistance and help with the statistical analysis of the data.

The **Agricultural Research Council** for their support in the statistical analysis of my data, especially **Marita van der Rijst**.

The **Western Cape Agricultural Research Trust**, **National Research Fund (NRF),** the **Protein Research Foundation (PRF)** and the **Oilseed Advisory Committee** for their financial support.

The **University of Stellenbosch** (Department of Animal Sciences) for their support during the course of the study.

The Directorate: Animal Science at Elsenburg for the use of their facilities.

Friends and **staff** at the **Department of Animal Science**, **University of Stellenbosch** for their help and support.

My family, especially my parents **Hennie** and **Comien Genis**, for listening to my complaints, for their encouragement and enthusiasm to finish the thesis.

The Lord for giving me the endurance, motivation, ability and the love of animal science to complete this study.

List of abbreviations

ADG	Average daily gain
BW	Body weight
CP	Crude protein
DE	Digestible energy
DFD	Dark firm dry
DM	Dry matter
DMI	Dry matter intake
FCR	Feed conversion ratio
GE	Gross energy
GI	Gastrointestinal
HCW	Hot carcass weight
HE	High energy diet
IVDOM	*In vitro digestible organic matter*
IVOMD	*in vitro organic material digestibility*
LD	*Longissimus dorsi*
LE	Low energy diet
LSD	Least significant differences
LSM	Least square means
ME	Metabolisable energy
ME	Medium energy diet
MJ	Mega joules
N	Newton
NDF	Neutral detergent fibre
pH_{45}	pH measured 45 minutes *post mortem*
pH_{48}	pH measured 48 hours *post mortem*
pHu	Ultimate pH
R 2	Coefficient of determination
SAMM	South African Mutton Merino
SE	Standard error
SM	*Semimembranosus* muscle
ST	*Semitendinosus* muscle
TMR	Total mixed ration
WBS	Warner Bratzler shear
WHC	Water holding capacity
ZH	Zilpaterol hydrochloride
β-AA	β-adrenergic agonists
β-AR	β-adrenergic receptor

TABLE OF CONTENTS

The thesis is a compilation of articles, therefore each chapter is an individual entity and repetition between chapters is there for unavoidable. This thesis' style is in accordance with the requirements of the *Journal of Meat Science*.

This work is based on the research supported by the South African Research Chairs Initiative of the Department of Science and Technology and National Research Foundation of South Africa. Any opinion, finding and conclusion or recommendation expressed in this material is that of the author(s) and the NRF does not accept any liability in this regard.

Parts of this thesis have been presented at:

1. 45th Congress of the South African Society for Animal Science, East London, July 2012, in the form of a poster and published in SAJAS.

1.1 Effects of dietary energy content and provision of β-adrenergic agonist on the production of feedlot lambs. T.S. Brand, M.P. Genis, L.C. Hoffman, W.F.J. van de Vyver & G.F. Jordaan. (2013). *South African Journal of Animal Science*, 43, 5, S135 – S139.

1.2 The effect of dietary energy and the inclusion of a β-adrenergic agonist in the diet on the meat quality of feedlot lambs. T.S. Brand, M.P. Genis, L.C. Hoffman, W.F.J. van de Vyver, R. Swart & G.F. Jordaan. (2013). *South African Journal of Animal Science*, 43, S140 – S145.

2. 46th Congress of South African Society for Animal Science, Bloemfontein, June 2013, in the form of a poster.

2.1 The effect of dietary energy and the use of a β-agonist on the sensory, physical and chemical characteristics of the meat of South African Mutton Merino feedlot lambs.

CHAPTER 1

GENERAL INTRODUCTION

The livestock industry of South Africa is subjected to constant change so as to satisfy consumer demands. Therefore the lamb production industry is an ever growing and changing industry. One of the biggest shifts in the industry in recent years is the shift of consumers to the consumption of leaner lamb carcasses (Hoffman *et al*., 2003). This change in consumer trend is largely due to a mind shift of the modern consumer towards eating healthier foods. This healthier shift of the consumer has led to new research strategies that include reducing the time lambs spend in the feedlot thereby reducing their fat accretion. Additional strategies in South Africa include the use of beta-adrenergic agonists (β-AA) even though none are yet registered with the Registration Holder (Intervet S.A. (Pty) Ltd; Reg. no. 1991/00658/07; Anon, 2013) in South Africa for the use in sheep. β-adrenergic agonists are predominantly used in the South African beef industry to promote lean yield and reduce the percentage of adipose tissue of the carcass.

Additional strategies to reduce the time spent in the feedlot include weaning lambs at higher body weight, use of older lambs, pre-weaning lambs with creep feed and alterations to the feedlot diet. Alterations to the feedlot diet typically revolve around the energy inclusion in the diet, since energy is the most important nutrient in the diet which will limit the performance of the lambs and also determine the fat deposition. Lambs display a higher feed intake when fed a pelleted diet (although it usually contains a higher level of roughages (Hart & Glimp, 1991; Paladines *et al*., 1963), whereas energy is found to be the first limiting factor of production (De Sousa *et al*., 1963; Maghoub *et al*., 2000). Feed intake of lambs that received high energy diets (2.90 Mcal ME/kg) was lower thant those that received low energy diets (2.90 Mcal ME/kg; De Sousa *et al*., 2012). Increased energy density diets therefore leads to decreased feed intake (Hossain *et al*., 2003; Sayed, 2011). The low energy level diet contained higher fibre contents, indicating that rumen fill could also affect feed intake. Contradictory to this, Abbasi *et al*. (2011) found that an increase in both the dietary metabolisable energy (ME) and crude protein (CP) not only showed an increase in the average daily gain (ADG) but the average dry matter intake (DMI) also increased. De Sousa *et al*. (2012) concluded that the higher energy density together with the lower neutral detergent fibre (NDF) content in a high energy diet attributed to the fact that these lambs had lower feed intakes, they've also found that the lambs on the low dietary energy level diet had a higher water intake which could be contributed to the higher amount of dry matter intake.

Although the energy density of a diet is seen as the first limiting factor of production, the voluntary feed intake of lambs is also influenced by various other factors. These factors include rumen fill, gastrointestinal (GI) health, palatability, physical form and composition of the diet (Paladines *et al*., 1963; Valderrabano *et al*., 2002). Overall, GI parasites are also known to decrease the voluntary feed intake of lambs, although this may vary according to the type of parasite as well as the interaction between the host and the parasite (Valderrabano *et al*., 2002).

As mentioned, South African producers use β-AA in feedlots which may result in the nutrient (energy) requirements of the lambs differing. Also, the overall energy requirements of wooled South African sheep has not yet been quantified satisfactory, nor has the effect of the various energy (and β-AA) levels on the meat (fat accretion) and wool quality been elucidated.

This study was thus planned to investigate the effect of dietary energy level, the inclusion of a β-AA and gender on South African Mutton Merinos finished in a feedlot. In the investigation, the lambs were fed three different dietary energy levels, either with a β-AA or not, to determine how the different levels of energy as well as the β-AA affects the production and quality (wool and meat) of the South African Mutton Merino lamb. The conceptual framework of the experiments is depicted in Figure 1. Two experiments were conducted, in the first, the effect of dietary energy, β-AA inclusion and gender were evaluated whilst in the second, dietary energy and gender were the main effects.

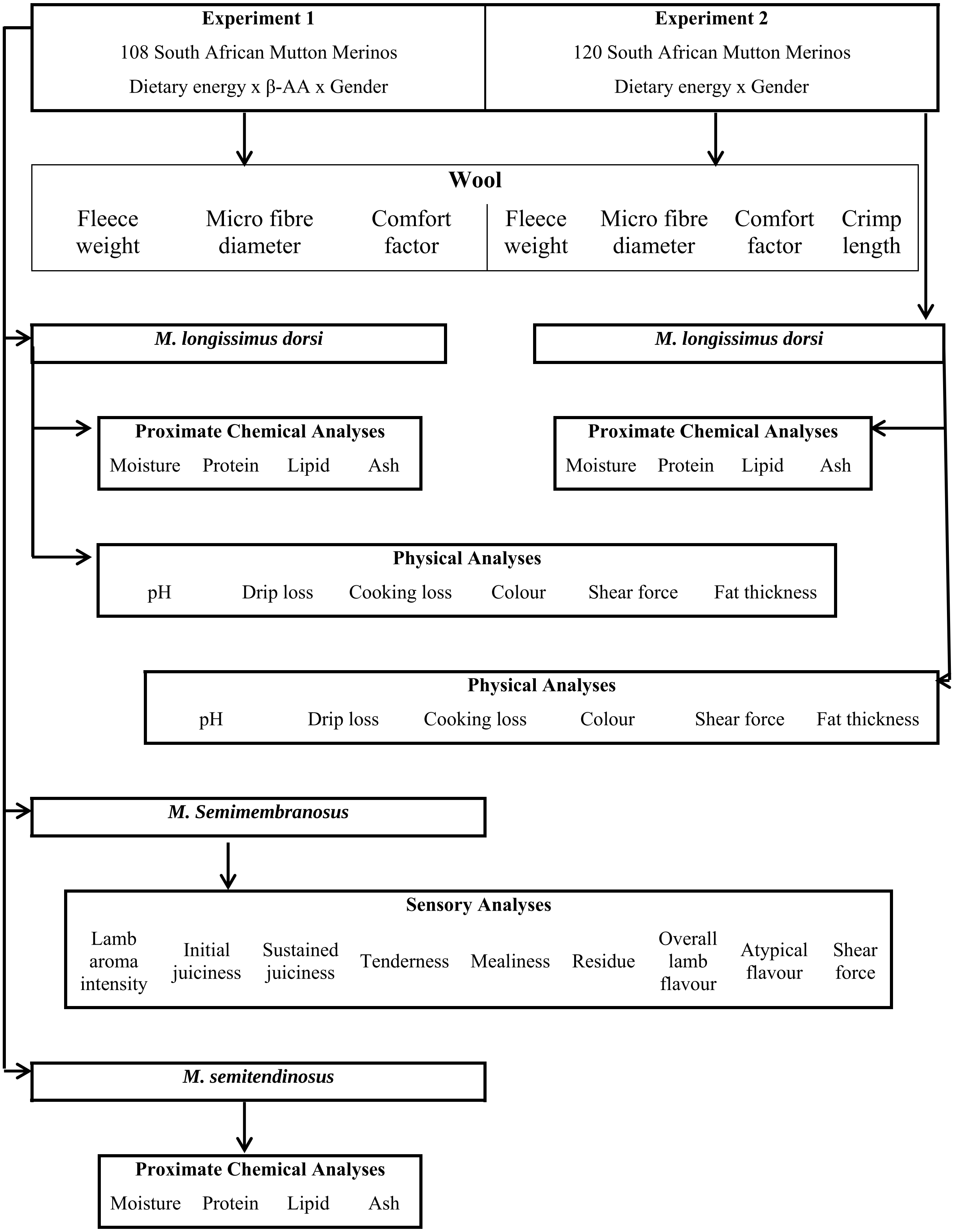

Figure 1.1 Conceptual framework depicting research aims

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Chapter 2

Literature review

2.1 Introduction

Recent increases in meat prices and the change in consumer preference towards leaner meat have resulted in more lamb producers opting to finish leaner mutton/lamb on farms in a feedlot system (Hoffman *et al*., 2003). Another aspect that has also occurred is where the sheep abattoirs have become more vertically integrated and are buying in young weaned lambs and finishing them off in their own feedlot – which is often adjacent to the abattoir. All these producers are looking to minimize their input costs which are predominantly made up of feed costs – in search for a better profit margin.

Yet very little information exists on dietary requirements for feedlotting South African lamb genotypes under local conditions as the whole production system is relatively new and the South African genotypes unique.

β-adrenergic agonists (β-AA) are commonly used in ruminant production to enhance meat production and decrease the fat content of the body. The β-AA normally improves growth performance and enhances a leaner carcass.

2.2 The South African Mutton Merino

The South African Mutton Merino (SAMM) was originally developed from the German Merino breed (an imported sheep breed; Cloete *et al*., 2004). The first German Mutton Merinos were imported from Germany to South African in 1932 by the Department of Agriculture (South African Mutton Merino Breeders' Society, 2012). The SAMM is a unique breed to South Africa, developed as a dual purpose mutton-wool sheep, which is highly adaptable to various regions of South Africa (South African Mutton Merino Breeders' Society, 2012; Neser *et al*., 2000). The development of this breed was intended to breed a lamb that has a heavy slaughter weight at an early age with good quality wool (Table 2.1; South African Mutton Merino Breeders' Society, 2012). This breed is described as a large framed, late maturing (deposits fat at a later age); well-muscled polled sheep with a pure white wool fleece (South African Mutton Merino Breeders' Society, 2012; Neser *et al*., 2000).

Table 2.1 Breed and performance information of the South African Mutton Merino

Production trait	**Averages (kg)**	
	Male	**Female**
Mature weight	127	77
Birth weight	4.1	3.8
100-day weight	32	29

(South African Mutton Merino Breeders' Society, 2012)

Commercially the SAMM is marketed directly to a abattoir or to a feedlot as soon as possible after weaning (Neser, 2000) or after a short fattening period; usually at a 20-30 kg live weight in Spain (Tejeda *et al*., 2008), although in South Africa lambs are slaughtered at heavier live weights (40-45 kg).

2.3 Lamb production

The most common production systems are the early-weaning of lambs and finishing them, either in a feedlot or on pastures, before slaughter. A feedlot is defined by Smith (2011) as an animal feeding operation, arranged in pens, used for fattening livestock prior to slaughter. In recent years the marketing and production sectors of the sheep industry have shown great effort and changes to enlarge the market while still supplying the consumer with quality meat (Figure 2.1; Costa *et al*., 2010). The primary objective of feedlotting is to maximize the gain of lambs to get them market ready as soon as possible. It is important to maintain a consistent good quality product to ensure consumer consumption and confidence (Duddy, 2007; Hopkins & Fogarty, 1998; Slusser, 2008).

Sheep and lamb, unlike beef and pork, are used worldwide by all religions and cultures, although some people find the odour and taste off putting when the meat is exposed to thermal treatment (Ivanovic *et al*., 2008). Although lamb consumption is much lower than poultry consumption in South Africa. Lamb is treated as a luxurious product due to its product characteristics (odour, taste) and the high price of the meat (Bas *et al*., 2000)

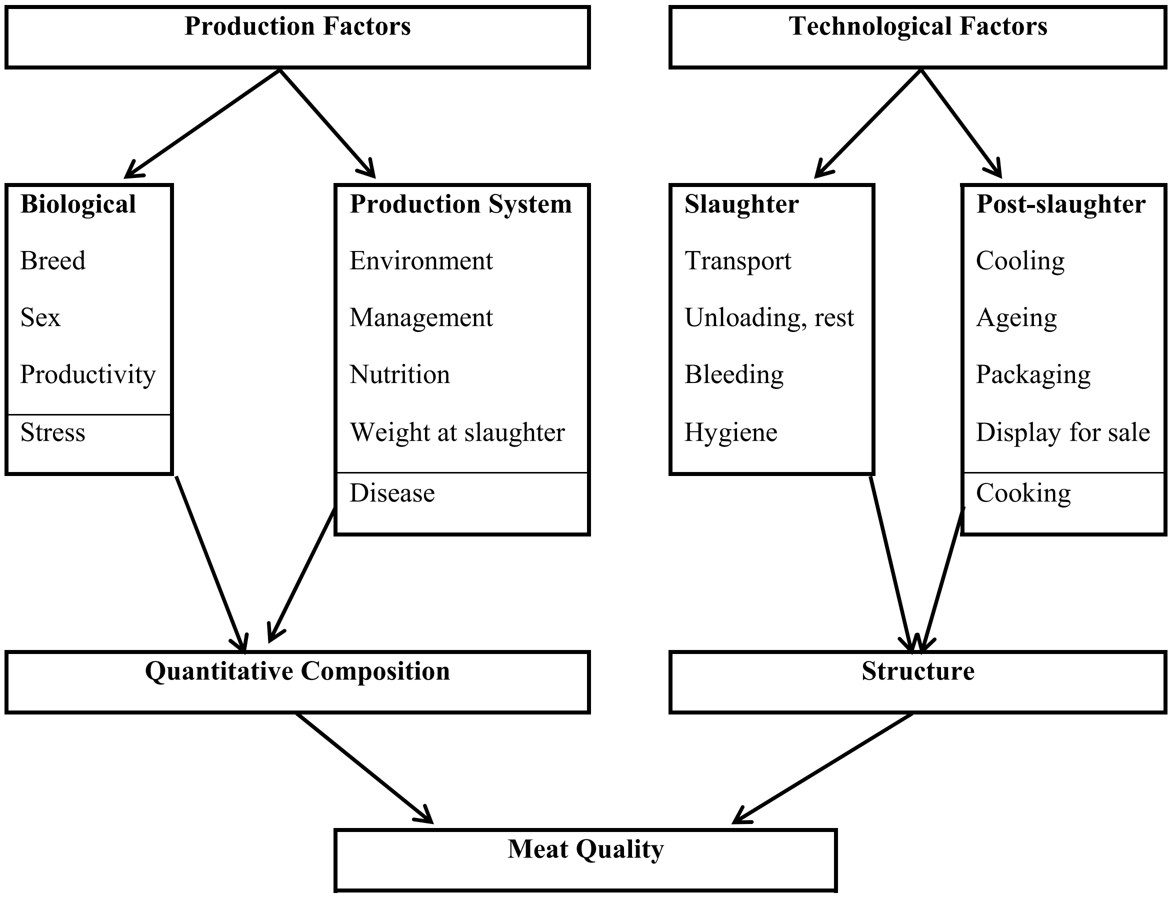

Figure 2.1 Factors affecting the meat quality of lamb/mutton (Beriain *et al*., 2003)

Celik & Yilmaz (2010) described meat quality as a compilation of undesired and desired characteristics of the meat consumed. Lamb quality is affected by various factors (Figure 2.1), these include gender, breed, age at slaughter as well as environmental factors such as the diet;whether the lambs were raised on pastures or concentrate based diets (Font i Furnols *et al*., 2009; Tejeda *et al*., 2008). Font i Furnols (2009) concluded that the acceptability of lamb is depended on the different lamb production systems and the consumers' consumption habits. According to Notter *et al*. (1991), forage-based production systems (extensive systems) have become more popular, since the consumer trends shifted to the consumption of a trimmer, leaner carcasses. The reason for this shift is that individuals have become more health conscious and aware of diseases such as coronary heart disease (CHD), which are associated with dietary animal fats (Chelik & Yilmaz, 2010; Fiems, 1987; Ponnampalam *et* *al*., 2001). It is however not recommended to cut meat totally from the diet since meat supply high quality proteins, trace elements, essential minerals and a range of vitamins (Ponnampalam *et al*., 2001).

The success of small stock production is dependent on consumer acceptability and the meat quality perception of the consumers (Hoffman *et al*., 2003). The acceptability of the meat for the consumer is largely dependent on toughness (chewiness and resistance), flavour and succulence (juiciness; Hoffman *et al*., 2003).

Production efficiency (Table 2.2) of a breed is preliminary dependent on reproductive efficiency (Malik *et al*., 2000), although other factors such as mothering ability, growth rate and feed efficiency ratios also plays a role.

Table 2.2 Average desired production efficiency of lambs in a well-managed feedlot

Production parameter	Average body weight 40 kg	Range 30-50 kg
Intake (kg DM/day)	1.6	1.0-1.8
Live weight gain (g/day)	250	200-320
Feed conversion	6.5:1	5:1-10:1

(Adapted from Duddy, 2007)

The following factors influence lamb production substantially (2.3.1 – 2.3.8):

2.3.1 Growth

Animal growth is achieved by hyperplasia (an increase in the number of cells) and hypertrophy (enlargement of cells) which leads to an increase in body weight (BW; Koohmaraie *et al*., 2002). Development of the animal body is achieved by changes in the body conformation, until maturity is reached (Lawrie, 1998). High protein (Table 2.3) and energy levels are required for growing lambs (Duddy, 2005). Excess energy in the diet, which was not used for lean growth and maximal bone development, is used for fat deposition (Murphy *et al*., 1994). Protein is especially necessary for normal rumen function and muscle development (Duddy, 2005). At any given energy intake level, as the lamb matures, the protein requirement decreases (Duddy, 2005). In the diets of lightweight lambs higher levels of 'bypass protein' is beneficial, while the protein requirements for older/larger lambs are normally met by cereal grain in the diet (Duddy, 2007). High production lambs need a certain amount of rumen non-degradable protein (Figure 2.3) to satisfy the protein requirements for maximum growth (Brand & van der Merwe, 1993).

Table 2.3 Crude protein requirements of feedlot lambs at different dietary energy levels and live weight

Ration energy MJ/kg DM	Lamb live weight			
	20 kg	30 kg	40 kg	50 kg
	Crude protein requirments %			
13	18.2	17.5	16.8	15.5
12	16.5	15.8	13.8	12.6
11	14.5	13.5	11.0	10.0
10	12.8	11.8	9.2	8.6

(Adapted from Duddy, 2005)

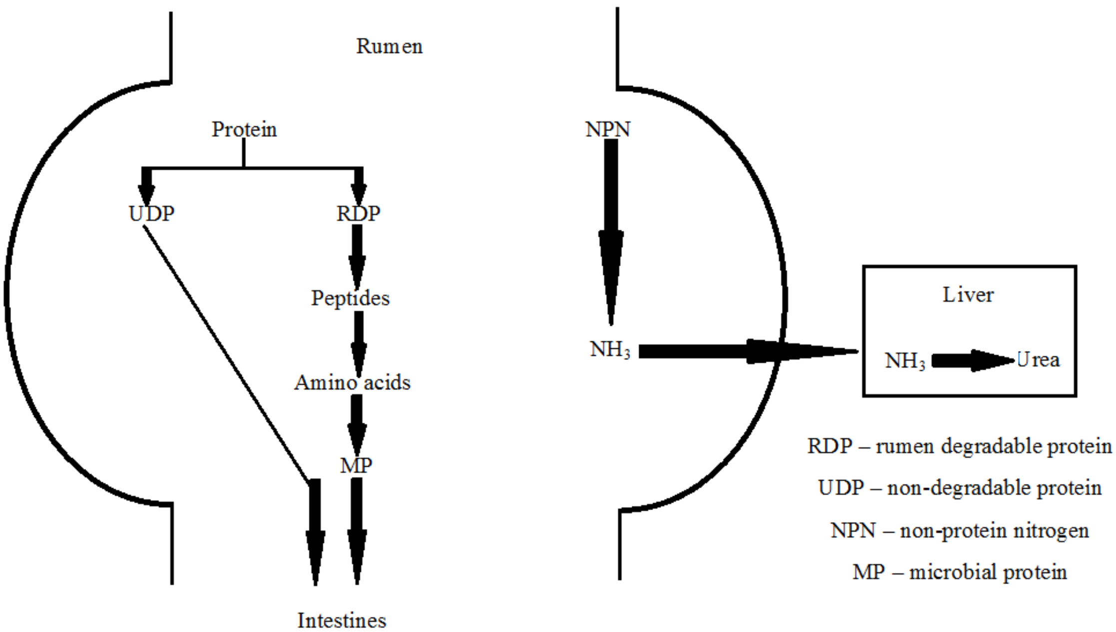

Figure 2.2 Schematic representation of the utilization of protein and NPN compounds by ruminants (adapted from McDonald *et al*. 2002)

Ideally the lambs should have at least a minimum growth of 300 g/lamb/day for the feedlot industry to be profitable (Anderton, 2005). When the lambs have a lower growth rate, they will spend more time in the feedlot, resulting in increased costs (Anderton, 2005). Growth performance is affected by dietary energy concentration (Beauchemin *et al*., 1995); an increase in dietary energy level results in an increase in growth rate. Decreased growth rate and feed efficiency increases costs of feedlot lambs and is likely to result in fatter carcasses (Beauchemin *et al*., 1995; Glimp & Snowder 1989).

2.3.2 Wool production

There are several factors that influence the amount of wool that a sheep can produce. These include nutrition (Table 2.4), breed, genetics and the intervals between shearing (Qi & Lupton, 1994; Sahoo & Soren, 2011). Crude protein is the most important nutrient in the diet of lambs that support wool growth. Gender plays a dominant role in the amount of wool any given sheep can produce especially when regarding the effect of gender on the mature size of the animal. Typically the ewe has a much smaller frame size than the ram and therefore she produces less wool than the ram. As mentioned before, the feed is the largest single cost in any given livestock production industry, therefore the feed must be carefully formulated to support all the production sectors of the sheep (both meat and wool).

Sahoo & Soren (2011) describes wool as a protein fibre that is composed mainly of amino acids, although small amounts of sodium, calcium and fat are also present. Both the quality (length, diameter, strength and protein composition) and quantity (total fleece yield) of wool decreases with a reduction in feed quality (either grazed or formulated diets). Therefore it is essential that the nutritional requirements for wool production are included in a maintenance diet.

Quality factor “wool diameter” is the major price determent of wool. Sheep on low nutrition planes tend to have a finer wool diameter (Sahoo & Soren, 2011). The most important nutrient for wool production is protein, especially amino acids cysteine and methionine, since wool is almost entirely composed of protein where the sulphur containing amino acids are prominent (Qi & Lupton, 1994; Sahoo & Soren, 2011). Wool growth is achieved by the elongation of fibres (staple length) and by the changes in fibre diameter (Sahoo & Soren, 2011).

The secondary price determent of wool is the staple strength and is a measurement of the amount of force (newton) that is required to break a staple of wool that has been corrected for linear density (the weight per unit length: kilotex; Sahoo & Soren, 2011).

Table 2.4 Nutrient requirement of sheep for wool production (g/day)

Body weight (kg)	DM (g)	DM (% of body weight)	Energy (TDN – g)	CP (g)	Ca (g)	P (g)	S (g)
20	730	3.1	330	40	1.5	1.0	1.7
25	870	3.5	390	47	1.7	1.1	2.1
30	1000	3.3	450	54	2.0	1.3	2.4
35	1100	3.1	500	60	2.2	1.5	2.6
40	1230	3.1	555	67	2.5	1.6	2.9
45	1350	3.0	610	73	2.7	1.8	3.2
50	1470	2.9	660	80	2.9	1.9	3.5
55	1580	2.9	710	85	3.2	2.1	3.8
60	1680	2.8	755	90	3.4	2.2	4.0

(adapted from Sahoo & Soren, 2011)

Restricted energy consumption leads to slower wool growth, reduced fibre diameter and weak spots in the wool (Sahoo & Soren, 2011). The quantity of protein included in the diet is more important than the quality of the protein, since the sheep can synthesize protein in the rumen from microbial produced amino acids (Sahoo & Soren, 2011). However, the sulphur-containing amino acids (cysteine and methionine) are important in the diet of wool producing sheep as they are an important component of wool fibre (Qi & Lupton, 1994).

Another important nutrient in the diet that influences wool growth is minerals. Marco-elements (required in large amounts) sodium (Na), potassium (K), sulphur (S), magnesium (Mg) and zinc (Zn) affects the feed intake and subsequently the wool growth. Sulphur, Na, K and cobalt (Co) alters the rumen function and therefore affects the supply of nutrients flowing from the rumen and subsequently wool production. Other minerals such as Zn, copper (Cu), selenium (Se), iodine (I) and Co directly disrupt the metabolism within the sheep and subsequently the rate of wool production.

2.3.3 Diet

The highest cost associated with feedlot sheep production is feed costs (satisfy the lambs' nutrient needs; Chiba, 2009). The typical feedlot ration consists of grain, forage and the required minerals and vitamins (Duddy, 2007; Slusser, 2008; Smith, 2011); therefore it is necessary to adapt the lambs to the ration. The feedlot lamb requires mainly protein, energy and fibre for it to be able to grow as economically as possible (Slusser, 2008). Energy is the largest portion of a diet and is frequently the first limiting nutrient in diets (Sahoo & Soren, 2011). Highly concentrated diets are fed to lambs in the feedlot, which increase the lambs' growth (Woolley *et al*., 2005). The efficiency with which the lamb converts feed resources into products such as wool and meat is an important factor of the lamb production industry (Chiba, 2009). When a complete feedlot diet is formulated the growth rate and efficiency can be improved by presenting the feed to the feedlot lamb in pellets (Esplin *et al*., 1957; Fontenot & Hopkins, 1965; Hartman *et al*., 1959). According to Jones *et al*. (1973), the feed intake of lambs decline when the diet contains less than 10% crude protein (CP), while intake is increased with increased fibre levels up until an inclusion level of 18.8%.

When comparing pasture raised lambs to concentrate based raised lambs, the pasture fed lambs have more varying flavours such as off-, rancid, lamb and livery flavours (Kemp *et al*., 1981; Priolo *et al*., 2002). A body of literature found that lambs fed diets high in energy (concentrate vs pastures with concentrate) produces meat that has more acceptable flavours compared to lambs fed pastures alone (Kemp *et al*., 1981; Locker, 1979; Summers *et al.,* 1981). Priolo *et al*. (2002) found that with an increase of the concentrate proportion in the diet the intramuscular fat of lambs increased. Increased protein and energy levels in the diet, result in an improvement of feed efficiency and an increase in the average daily gain (ADG; Craddock *et al*., 1974; Ebrahimi *et al*., 2007). Higher growth rates are accomplished when feed is available to lambs at all time (*ad libitum*), improving overall feedlot efficiency (Duddy, 2007).

When lambs that were fed a high (and low) concentrate diet are slaughtered at the same live weights, diet only seems to affect the carcass dressing percentage and growth rate, with a limited effect on carcass leanness (Beauchemin *et al*., 1995). Beauchemin *et al*. (1995) found that lambs that receive a moderate dietary energy level (13.39 DE MJ/kg feed) had a decreased growth rate which had very little effect on carcass leanness (Haddad & Husein, 2004). Feed intake decreases with an increase in energy level and increases with an increase in protein level in the diet (Crouse *et al*., 1978).

Inadequate dietary energy levels limit the performance of lambs more than any other nutrient in the lamb's diet (Chiba, 2009). Lambs that receive a total mixed ration (TMR; 70% concentrate and 30% forage) can be slaughtered at an earlier age before fat deposition starts (especially when using late maturing lamb breeds; Costa *et al*., 2010). Ebrahimi *et al*. (2007) found that an increase in protein levels in high energy diets decreases fat measurements while it increased on low energy diets. Increased protein and energy dietary levels increase both

ADG and feed efficiency (Ebrahimi *et al*., 2007). A finishing diet with 10-11ME MJ/kg DM feed is sufficient to boost the muscle glycogen concentration, under *ad libitum* conditions, for premium meat quality (Jacob & Gardner, 2008). Ideally a lamb should be younger than a year and still be growing at slaughter for optimal financial return.

The producers' biggest challenge is to meet the energy requirements of the animal without under- or over feeding (Sahoo & Soren, 2011). Energy deficiencies manifest itself in reduced growth, weight loss and death. Restricted feeding programs can be used to decrease the amount of carcass fat and increase the percentage of edible lean meat (Murphy *et al*., 1994). Excess of dietary energy (excessively high energy diets) cause lambs to scour (diarrhea) and the meat to have soft fat and an off flavour (Jacob & Gardner, 2008).

2.3.4 Gender

The gender of lambs influence a number of production factors such as the growth rate, body composition, feed conversion ratio (FCR) and the meat quality (Rodriguez *et al*., 2008). According to Butterfield (1988), rams mature slower than the ewes, while the ewes fatten up earlier than the rams (the different maturation rate of sexes influence the growth curve significantly (Figure 2.3); Crouse *et al*., 1981). Johnson *et al*. (2005) found that ewe lambs have a higher dressing percentage than ram lambs, while Notter *et al*. (1991) reported that wethers grow slower than rams but faster than ewes.

Feed utilization of rams (intact males) is more efficient than either the wether or ewe (Arnold & Meyer, 1988; Crouse *et al*., 1981). Sex hormones plays a major role here, by influencing the growth pattern (Cloete *et al*., 2012).The use of ram lambs, as meat producing animals, satisfies the consumer trend for increasing leanness (Notter *et al*., 1991). These lambs will be slaughtered at a younger age than their wether and ewe counterparts when produced on forage-based diets. Seideman *et al*. (1984) found that the intact ram lamb is a more desirable meat producing animal – grows faster, utilizes feed better and produces a heavier carcass with less fat leaner red meat than castrates. An unfortunate effect from ram production is that they tend to be less tender and have undesirable odours and flavours when compared to wethers when cooked (Seideman *et al*., 1984). The age at which the ram lamb is slaughtered is an important factor when it comes to aspects such as odours and flavours although no difference if any would be detected between genders at an age of 4-5 months because sexual maturity have not been reached.

Due to the larger mature size of rams, compared to their ewe and wether counterparts, they tend to produce more wool (Khan *et al*., 2012), while the annual fleece growth of ewes are reduced during reproduction. When environment and nutrition factors of rams are kept at a constant the micron of wool increase until an age of about 2-2.5 years where after a plateau is gradually reached (Anon, 2011).

2.3.5 Age

Ageing of the lamb leads to the maturation of the tissues. The order in which the tissue mature is bone, muscle and fat (Rouse *et al*., 1970). Also, the tenderness of the meat decrease as the age of the animal increases (Wenham *et al*., 1973).

Figure 2.3 is an indication of how the different tissues of the body develop in either an early maturing animal or an animal that receives a high plane of nutrition (a) or a late maturing animal or an animal that receives a low plane of nutrition (b). The growth curves indicate the order of development as follow (Lawrie, 1998):

growth curve 1:	head, brain, cannon & kidney fat
growth curve 2:	neck, bone, tibia-fibular & intermuscular fat
growth curve 3:	thorax, muscle, femur & subcutaneous fat
growth curve 4:	loin, femur, pelvis & intramuscular fat

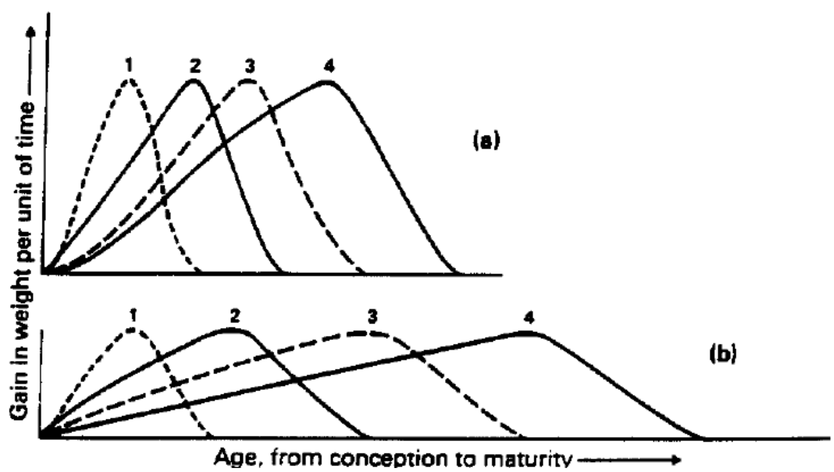

Figure 2.3 The development of different body tissues in the early (high feeding plane; a) and late (low feeding plane; b) maturing animal (Lawrie, 1998)

According to Van der Westhuizen (2010), the chronological age of the lamb is a major effect in animal production – also, with an increase in age the animal flavour in meat intensifies/increases (Sink & Caporaso, 1977).

2.3.6 Live weight

The lower slaughter weight of ewes, when compared to the slaughter weight of the rams, could be caused by the differences in mature size and growth rate between rams and ewes (Kirton *et al*., 1995). When lambs are divided into pens according to size and live weight, stress is reduced in the feedlot environment (Duddy, 2007). Martinez-Cerezo *et al*. (2005) concluded that consumers of Mediterranean countries prefer meat from light lambs, these consumers believe that the meat from lighter lamb carcasses are of better quality even though they have less flavour and are more tender when compared to heavier animals. With increased carcass weights, dressing percentages also increase (Kemp *et al*., 1976).

2.3.7 Fat deposition

Fat is laid down in various sites in the body in cells. The various depots in which fat is laid down in, is subcutaneous (fat immediately under the skin), intermuscular (lies between the muscle), intramuscular (lies within the muscle) and deposits surrounding organs (e.g. kidney, caul and heart). Fat is a late maturing tissue, as the animal ages muscle growth slows down, bone growth ceases, and fat growth continues (Figure 2.3; Thu, 2006). Generally it is accepted that the energy concentration of a diet influence the fat deposition. Field (1971) established that a feedlot diet enable rams to fully reach their superiority in growth potential compared to ewes and castrates, which leads to an increased fat content and decreased muscle:moisture content of the carcass (French *et al*., 2001).

According to Jeremiah *et al*. (1997), when the same level of husbandry is applied to ewes and rams, it is accepted that the ewes will be fatter than the rams. On visual appearance alone, 50% of consumers regard lamb chops as too fat (Jeremiah *et al*., 1993). Fat deposition can be decreased by means of intake restriction or by feeding a high forage diet rather than a high concentrate diet, resulting in lambs reaching their target weight later and an increase in production cost (spend more time in the feedlot; Leymaster & Jenkins, 1985). An increase in dietary energy level results in an increase in fat deposition (Ebrahimi *et al*., 2007; Table 2.5).

According to Lambuth *et al*. (1970), there is an increase in fat deposition as the animals approach the top of their growth curve. With an increase in fat percentage there is a decrease in the bone percentage – explaining the decreased bone percentage with an increased slaughter weight. The cutability (proportion of carcass that is saleable) also decreases as the carcass fat percentage increases (Ray & Mandigo, 1966).

Table 2.5 Effect of energy intake level on muscle:bone:fat ratio of lambs on restricted feed intake

Component	**Intake level, % of *ad libitum***		
	100	**85**	**70**
Bone	17.69	18.30	18.13
Muscle	45.10	48.19	49.12
Bone	17.69	18.30	18.13
Fat	37.21	33.51	32.75

(Adapted from Murphy *et al*., 1994)

2.3.8 Carcass composition

Costa *et al*. (2010) define carcass conformation as the thickness of muscle and subcutaneous fat in relation to the skeleton size or as the visual impression that the observer forms of the carcass. The carcass consists primarily out of bone, muscle and fat (Cloete *et al*., 2004). Animal development occurs in a certain sequence with the first wave of development starting at the head spreading down towards the trunk and with the second development phase starting at the limbs and moving upwards (van der Westhuizen, 2010; Figure 2.4). The muscle (especially in developed countries) is seen as the most important tissue to the consumer (Cloete *et al*., 2004). The appearance of muscle and fat, taking in consideration the weight of the carcass, determines the commercial value of lamb carcasses (Beriain *et al*., 2000).

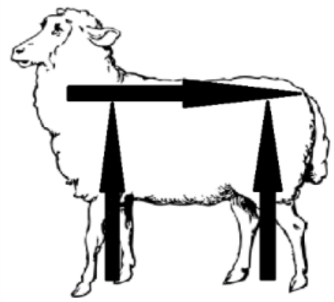

Figure 2.4 An illustration of development sequence of the animal body (adapted from Lawrie, 1998)

The hindquarters (loin and hind leg) are among those muscles that contribute to higher priced cuts. These cuts are higher priced due to the higher muscle to fat and connective tissue ratios (Thonney *et al*., 1987). The difference tissue ratios (bone:muscle:fat) is the reason for the production and importing of different maturing breeds (Cloete *et al*., 2004). Costa *et al*. (2010) found that the energy density of diets influence the muscle:fat ratio; the lamb that accumulated more total carcass fat would typically have received the higher energy level diet.

When carcasses (slaughtered on average 160 days of age) of ram and ewe lambs of the same age were compared, the ewes were better developed in the hindquarters while the rams were more developed in the front quarters (head and neck area; Fahmy *et al*., 1999; Johnson *et al*., 2005; Wolf *et al*., 2001). Purchas (1978) found that ewes yield a higher carcass than rams when they were slaughtered at the same live weight, despite the differences in their growth rates. Kirton *et al*. (1995) noted that ewe lambs deposit more total carcass fat and have larger individual fat depots compared to ram lambs at the same age.

Johnson *et al*. (2005) determined the value of a lamb carcass as the yield of lean meat. The value of the lamb is furthermore also influenced by the quality as well as the distribution of the yield of lean meat on the lamb's carcass.

According to Costa *et al*. (2010), the consumer market sees carcass weight as a predetermined factor as a quality indicator. The modern consumer is very health conscious; therefore the amount of fat is an important aspect (Haley, 2001; Putnam & Allshouse, 2001). According to Beermann *et al*. (1995), of all the lamb meat produced in the United States only 30% meet the consumer requirements. Tejeda *et al*., (2008) concluded that meat from heavier lambs is considered to have lower quality (less tender and more intense flavour) than light lambs.

2.4 β-adrenergic agonists

The use of anabolic agents is another method other than nutrition and selection (crossbreeding) to enhance growth efficiency of livestock (Fiems, 1987). β-adrenergic agonists (β-AA) show strong similarities to adrenalin (Fiems, 1987).

2.4.1 Mode of action

Zilpaterol hydrochloride (ZH; Figure 2.5) is classified as a type 2 β-agonist registered for feedlot cattle at an average of 8.3 mg/kg DM diet during their final days in the feedlot (Robles-Estrada *et al*., (2009). The final days is either the last 20 or 40 days spent in the feedlot, followed by a withdrawal period of 3 days, prior to slaughter (Robles-Estrada *et al*., (2009). According to Fiems (1987), the positive effects of β-AA on FCR and growth rates can be reduced if used for too long a term on end.

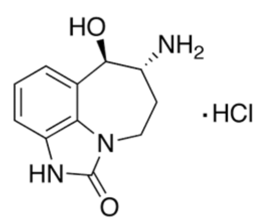

Figure 2.5 Chemical structure of zilpaterol hydrochloride (adapted from Fiems, 1987)

The β-AA binds to the β-adrenergic receptor (β-AR) resulting in a physiological response (Mersmann, 1998). Epinephrine and norepinephrine are the physiological β-AR agonists in the animal (Mersmann, 1998). When a β-AA is fed to the animal a series of functions occur: enhanced glucagon secretion with an inhibition of glycogenolysis, lipolysis, gluconeogenesis and insulin secretion (Figure 2.6 the mode of action of a β-AA; Fiems, 1987). When a β-AA is fed to an animal the feed intake generally decreases. The β-AA decrease both protein degradation and lipogenesis, it also increases both protein synthesis and lipolysis (McNeel & Mersmann, 1995; Mersmann, 1998) and as a result carcass fat is reduced (Fiems, 1987). Zilpaterol hydrochloride is given orally to livestock (Elam *et al*., (2009).

In short the β-AA enhances growth by an inhibition of proteolysis (muscle tissue breakdown) and promotes lipolysis (adipose tissue breakdown; Plascencia *et al*., 1999), although proteolysis is inhibited, the protein synthesis' rate is not affected per se.

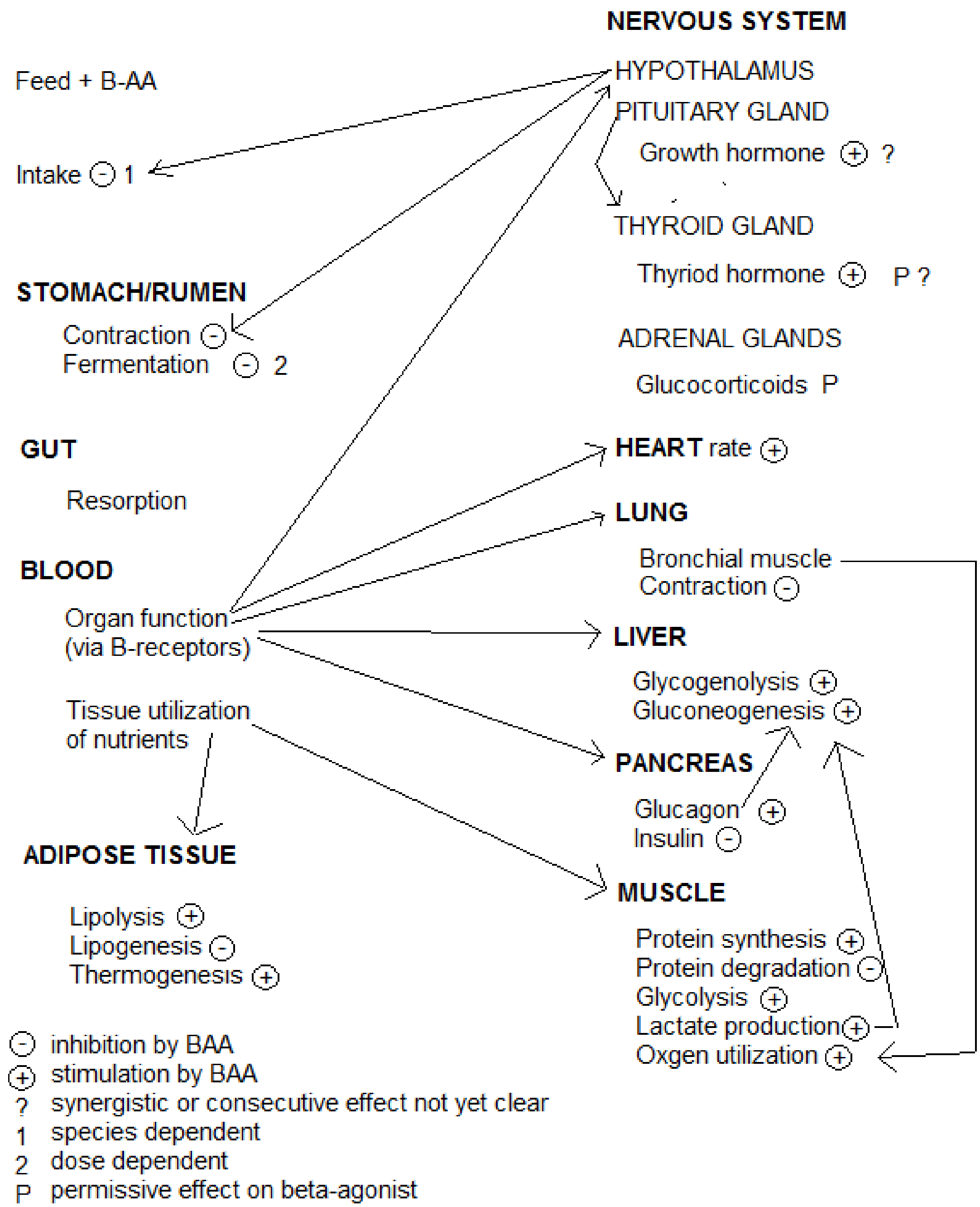

Figure 2.6 Illustration of the mode of action of a β-AA (adapted from Fiems, 1987)

2.4.2 Legislation

According to Montgomery *et al*. (2009), ZH is a relatively new pharmaceutical product, which is commercially distributed in the United States, South Africa and Mexico (Elam *et al*., 2009). β-AA have been used since the 1990s in production cattle feedlots in Mexico (1999) and South Africa (1997), more recently the use of ZH has been approved in Canada (2009) on beef cattle (Delmore *et al*., 2010). According to Delmore *et al*. (2010), the use of ZA in beef cattle was approved by the US Food and Drug Administration in August 2006 but was only commercially used from May 2007 in the United States. In 2006, Intervet received FDA approval for the use of Zilmax® (Mexico and South Africa; Beermann, 2006). However Zilmax® is a costly additive to include in a diet and should therefore be used as recommended.

2.4.3 Effect

When feeding a β-AA to livestock it typically increases the ADG and improves feed efficiency (Beckett *et al*., 2009; Casey *et al.* 1997; Eckerman *et al*., 2011; Elam *et al*., 2009; Lopez-Carlos *et al*., 2010; Mersmann, 2002; Montgomery *et al*., 2009; Parr *et al*., 2011; Rathmann *et al*., 2009), decreases adipose tissue and increases skeletal muscle (Byrem *et al*., 1998; Holland, 2010; Lopez-Carlos *et al*., 2010; Mersmann, 1998, 2002; Rathmann *et al*., 2009). The ADG is an important economic factor because this influences the time the lamb will spend in the feedlot and consequently the economic return (O'Neill, 2001). The increase in skeletal muscle is largely due to a hypertrophic increase in the fibre diameter of the muscles (Avendano-Reyes *et al*., 2006), an unfortunate side effect of the fibre diameter increase is that the meat tenderness is compromised (less tender).

Elam *et al*. (2009) found that β-AA decreased the total carcass fat in cattle whilst Avendano-Reyes *et al*. (2006) found that the use of ZH increase both the HCW (hot carcass weight) and the dressing percentage (Beckett *et al*., 2009). However, Arnsperger *et al.* (1976) found that the use of β-AA could increase the risk of anal prolapse. With the use of a β-AA the muscle weight can be increased up to 40% (Beermann, 1993; Mersmann, 1998), although the weight increase varies from muscle to muscle (Beermann, 2002).

Montgomery *et al*. (2009) found that the ZH decreased steers' DM intake (~2%), while their ADG were increased. Elam *et al*. (2009) had a 9 kg higher final BW with the use of ZH and approximately a 15 kg increase in the hot carcass weight (HCW) in cattle. Montgomery *et al*. (2009) also found that heifers had a higher final BW compared to heifers who did not receive the ZH treatment. Hilton *et al*. (2009) found that the cutability of boneless cuts was increased with the treatment of ZH. According to Hilton *et al*. (2009), the use of ZH decreases the sensory tenderness of the meat as well as increases the shear force. On the other hand, Delmore *et al*. (2010) found that the changes in tenderness, due to the use of ZH, had a minimal effect on the consumer acceptance of beef. Leheska *et al*. (2009) found that the use of ZH mostly affects the carcass bone, moisture and ash percentages and rarely the fat:protein ratio. Although a study by Delmore *et al*. (2010) found that the cattle in the ZH treatment groups had more moisture and protein when compared to the control group. While both Hilton *et al*. (2009) and Lawrence *et al*. (2011) found that the carcass fat between the 9th and 11th ribs was significantly decreased (Lawrence *et al*., 2011).

However, very little work has been published on the use of ZH in sheep. Shelver & Smith (2006) conducted a trial in Mexico, mixing 15 mg/kg BW/day (level used and recommended by the industry) in a sheep feedlot trial, and found that after a 2 day withdrawal period, an average of 5% of the initial zilpaterol concentration remained in the tissues. Baker *et al*. (1984) found that the effect of the β-AA to be more profound in more mature lambs (older lamb).

2.5 Physical, sensory and chemical characteristics of meat

2.5.1 Post-mortem pH

The muscle pH is an important factor that determines the quality of the meat during the transformation from muscle to meat (Bas *et al*., 2000; Beriain, 2003). Organoleptic characteristics are influenced by the changes in pH *post-mortem* (Bas *et al*., 2000). Post mortem (after death) the glycogen stores in the muscle are converted into lactic acid anaerobically (Warriss, 1990). The initial pH after slaughter is generally around 7.0, and the conversion of glycogen to lactic acid causes a drop in the pH to an ultimate pH (pH_u; Figure 2.7) of around 5.5 (Warriss, 1990). This drop occurs in 24-48 hours *post mortem*. The pH_u reached *post-mortem* is depended on *ante mortem* conditions (stress could deplete glycogen levels and a higher pH_u is reached; Warriss, 1990). The organoleptic characteristics of the meat are influenced in the *post-mortem* period, during the pH changes (Beriain, 2003).

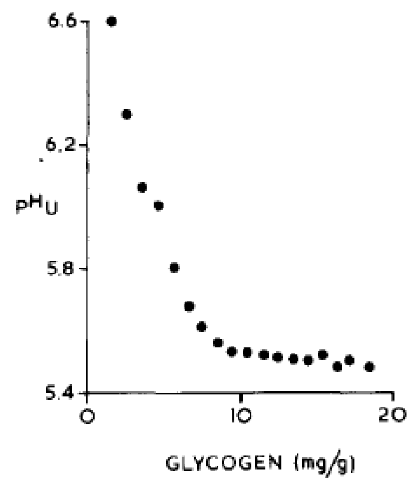

Figure 2.7 The relationship of glycogen concentration present in the muscle to pH_u (adapted from Warriss, 1990)

Hopkins & Fogarty (1998) found that lambs with a high muscle pH had more foreign flavours than overall lamb flavour in the meat. Devine *et al*. (1993) found that the ultimate pH is an important meat quality indicator, pH values higher than 5.8 are undesirable. Figure 2.8 is a representation of undesirable meat quality due to the pH_u; dark, firm, dry meat is a result of a to high pH_u.

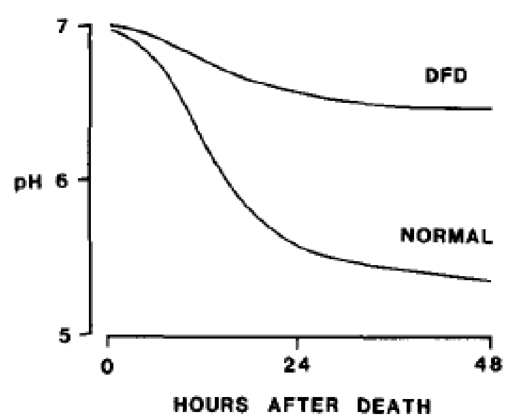

Figure 2.8 Schematic representation of the fall in pH *post-mortem* (Warriss, 1990)

Dark firm dry (DFD) meat occurs when the concentration glycogen in the *ante mortem* muscle are to low (Gardner *et al*., 1999) and consequently results in a high pH_u. Stress *ante mortem* results in a high pH, this affects meat colour more than any other pre-slaughter factor (Bas *et al*., 2000). A high pH also results in a strong binding of the proteins and water, therefore less juice is released during mastication which causes a low quality, dry meat (Bas *et al*., 2000). A low pH_u is desired (5.5) because it is associated with improved palatability and lighter-coloured meat (Gardner *et al*., 1999).

2.5.2 Tenderness

Tenderness is defined as the ease at which the meat is chewed, stretched or cut (Anon, 2013; Bas *et al*., 2000). The tenderness of the meat is greatly affected by the type and amount of connective tissue, especially collagen, in the meat. Immediately *post-mortem*, the meat is tender, as the meat ages a progressive softening of the muscle occurs, tenderness thus intensifies with ageing (Devine & Graafhuis, 1995; Ivanovic *et al*., 2008; Figure 2.9). The meat from ewes is also more tender than the meat from rams; this is due to the influence of the hormone testosterone (Bas *et al*., 2000). Testosterone increases the amount of collagen. Marbling is also related to the tenderness of the meat (Schonfeldt *et al*., 1993; Smith *et al*., 1976). Kemp *et al*. (1981) found that a high plane of nutrition leads to an increase in intermuscular fat with a relative decrease in collagen which leads to a more tender meat. With an increase in animal age there is also an increase of collagen which consequently leads to a decrease in tenderness (Kemp *et al*., 1981).

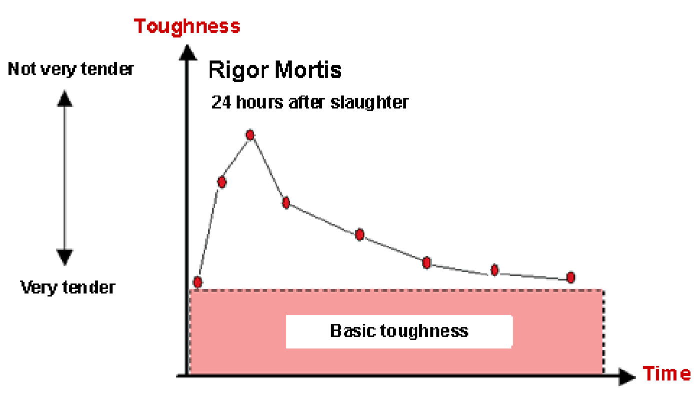

Figure 2.9 The effect of ageing on meat tenderness (Anon, 2013)

The tenderness of the meat is measured by means of the Warner-Bratzler shear force measurement, ram lambs tend to have higher values (their meat are less tender; Johnson *et al*., 2005). The Warner-Bratzler shear force measurement is used because of the high costs of a sensory panel (the panel need to be trained beforehand) and due to the high correlation that is frequently found between these two measurements (Safari *et al*., 2001). Tenderness is a major factor contributing to eating quality and consumer preference (Hopkins & Fogarty, 1998; Safari *et al*., 2001).

2.5.3 Colour

The colour of meat is the most important factor that influences the consumer's purchasing intent at the time of purchase (Kerry *et al*., 2000; Martinez-Cerezo *et al*., 2005), unless any odours were detected first (Tejeda *et al*., 2008; van der Westhuizen *et al*., 2010). Martinez-Cerezo *et al*. (2005) found that the colour of meat is both influenced by the breed and the live weight of the lamb. Sanudo *et al*. (2005) also showed that with an increase in slaughter weight, a decrease in meat lightness occurred. Colour in meat depends on the myoglobin content and the degree to which the myoglobin is oxidized (Anon, 2013). With an increase in age the myoglobin concentration increases which leads to increased colour intensity (Bas *et al*., 2000). Consumer preference to colouring varies from country to country.

According to Stevenson *et al*. (1989) the best colour analysis is with the CIELab colour space. This instrument expresses the colour according to the L^*, a^* and b^* ordinates (Table 2.6).

Table 2.6 CIELab colour ordinate descriptions

Ordinate	**Scale**	**Description**	
L^*	0 – 100	0 – pure black	100 – pure white
a^*	$-a^*$ & $+a^*$	$-a^*$ - greenness	$+a^*$ - redness
b^*	$-b^*$ & $+b^*$	$-b^*$ - blueness	$+b^*$ - yellowness

(Adapted from van der Westhuizen, 2010)

Priolo *et al*. (2002) found that lambs reared in an extensive production (lambs on pastures) system's meat were darker in colour compared to lambs in an intensive production system (fed a concentrate diet). Jacobs *et al*. (1972) found that with an increase in age and live weight the colour of the meat intensifies. This occurrence is partially due to the fact that lambs that were fed a grass diet have a higher pH_u than lambs fed a concentrate diet; the latter would most probably have had higher *ante mortem* glycogen levels in their muscle. According to Lawrie (1998), with an increase in live weight the L^* (lightness) and b^* (yellowness) coordinates decrease while the a^* (redness) coordinate increases. This change in colour is due to the increase of haem pigment as the animal ages. Weaned lambs also have a darker meat colour than suckling lambs, this is due to the low iron content of ewe milk (Bas *et al*., 2000). Contradictory to this, Ponnampalam *et al*. (2001) found that the colour of the meat was not significantly influenced by diet. However they did find that different days of ageing (of the meat) had significant effects on the colour value a*, although the 6th day of ageing had the same a* value as fresh meat.

Jacob & Gardener (2008) found that supplementing vitamin E (2-4 weeks prior to slaughter) in the diet improved shelf life and caused the meat to be lighter, which is favourable since consumers prefer light meat to dark meat.

2.5.4 Flavour

Flavour is a compilation of both taste (perceived by taste buds during chewing) and odour (perceived by the nose once the sample is in the mouth; Anon, 2013). Abd El-aal & Suliman (2008) described flavour as the main characteristic, during evaluation that determines the acceptability of the meat for the consumer. The flavour of meat is greatly affected by the freshness, quantity and composition of the fat. Here the diet of the animal plays a role since the diet alters the composition of fat. The species flavour of meat (flavour specific of each species) originates in the fatty tissue of the animal (Melton, 1990). The fat in the meat acts as a solvent, during cooking, for the volatile compounds which accumulate (Moody, 1983). Melton (1990) found in a study that lambs fed a concentrate (higher in energy) diet had more acceptable flavour, compared to lambs on pastures (lower in energy).

Basically the flavour, as presumed by the consumer, is reliant on components which are soluble in water (Ivanovic *et al*., 2008), such as sugars, amino acids and nucleotides (Bas *et al*., 2000). The flavour is also influenced by the proportion of lipids and fatty acids in the meat which is characteristic for each species. Ivanovic *et al*. (2008) found that with ageing flavour intensifies. However, fat is also prone to oxidation and the development of rancid off-flavours. For example, myoglobin oxidation causes rancidity of meat (Ponnampalam *et al*, 2001), which makes it undesirable for consumers.

2.5.5 Juiciness

Juiciness is defined as the quantity of water that is preserved in the meat sample after cooking, which is released when chewed (Anon, 2013). A second sensation of juiciness is the slow release of serum and secretion of saliva by the salivary glands (stimulated by fat; Bas *et al*., 2000). Meat contains 75% water. As soon as the animal is slaughtered the animal starts to loose water. Different cooking methods causes variable water loss; during boiling of meat it can lose 40%, roasting 30% and grilling (Anon, 2013). A high pH_u leads to dry meat (low juiciness) because it results in strong binding between proteins and water, therefore only a small amount of water is released during mastication (Bas *et al*., 2000).

The amount of energy in the diet influences the juiciness of the meat. Animals that were finished on adequate energy diets had more juicy meat compared to animals that were finished on inadequate amounts of energy diets (Figure 2.10; Jacob & Gardner, 2008). Contradictory Batista *et al*. (2010) found that a diet with a lower energy concentration provides juicier meat (10.46 MJ ME/kg DM vs. 12.56 MJ ME/kg DM). Fat is an essential component for the sensory perception of texture, flavour and juiciness (Moloney, 2002). Moloney (2002) concluded that red meat could contain up to 25-50 g/kg intramuscular fat concentration and still be considered a low fat food. Bruwer *et al*. (1987) found that very lean carcases (low percentage of intramuscular fat) were significantly less juicier than the meat of fatter carcasses (higher percentage of intramuscular fat).

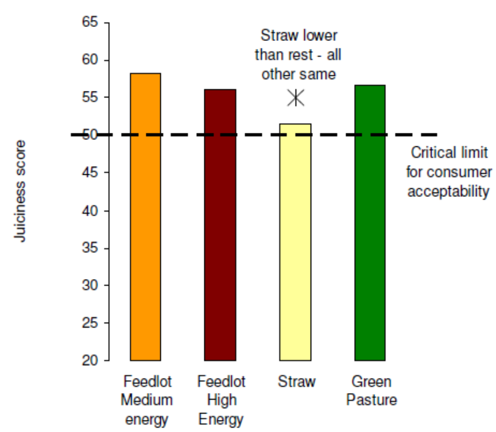

Figure 2.10 The effect of finishing diet on lamb meat juiciness (adapted from Jacob & Gardner, 2008)

2.5.6 Moisture

The mean fat content in meat of different species is 10-27% (Celik & Yilmaz, 2010). Offer & Cousins (1992) found the moisture to be located in the muscle (later shown to be within the myofibrils by Hoffman *et al.,* 2003) and with an increase in intramuscular fat content a decrease in the water level in the muscle occurs (Huff-Lonergan & Lonergan, 2005). Approximately 75% of lean muscle is water (Huff-Lonergan & Lonergan, 2005), the remainder consists of protein, lipid, vitamins and minerals. Martinez-Cerezo *et al*. (2005) found that both the water (moisture) and intramuscular fat content affects the tenderness of the meat. With an increase in slaughter weight a decrease in moisture content of the meat is observed (Martinez-Cerezo *et al*., 2005). The moisture content of meat is determined by weighing (2.5 g) a sample and drying it for 24 hours at 100°C (AOAC, 2002, Method 934.01).

Over the first two days of chilling, the amount of drip lost generally is 1-10 ml/kg meat (1-3% in fresh cuts; Huff-Lonergan & Lonergan, 2005; Offer & Cousins, 1992; also refer to section 2.5.7). Drip loss leads to a poorer carcass appearance and a financial loss, due to a lighter marketable product.

Water is a bipolar molecule (attracted to other charged molecules), which is closely bound to protein (Huff-Lonergan & Lonergan, 2005). The water bound to protein in the meat is less than a tenth of the total amount of moisture in the meat. Another fraction of the water in the meat that is trapped within the structure is also known as immobilized water (Huff-Lonergan & Lonergan, 2005). This water is mostly affected by rigor (water loss and drying out) and easily converted to ice. Large ice crystals change the meat's quality and can ruin the taste – this should be avoided.

2.5.7 Protein

Approximately 20% of lean muscle is protein (Huff-Lonergan & Lonergan, 2005), whereas Celik & Yilmaz (2010) determined the mean protein present in meat of different species to be 17-20%. The protein content of the meat is determined with the LECO combustion method

(AOAC, 1992, Method 992.15). When a cut is made, at any place, a solution known as drip, oozes from the carcass (Offer & Cousins, 1992). About $^2/_3$ of the total protein concentration (140 mg/ml) in the carcass, or meat sample, is lost in this drip (Huff-Lonergan & Lonergan, 2005).

2.5.8 Lipid

Approximately 5% of lean muscle is composed of lipids (Huff-Lonergan & Lonergan, 2005). Increased age at slaughter has a linear tendency to increase the fat content of the meat (Martinez-Cerezo *et al*., 2005). Fat has low water content. The source of flavour in meat is predominately fat (fatty acid composition of the fat; Thu, 2006). The fat content of meat is determined by the methanol:ether extract method on a 5g piece of sample meat (Lee *et al*., 1996).

2.5.9 Ash

Approximately 1% (0.8-1.3%) of lean meat (of different animal species) is minerals, which are analysed as the ash (Huff-Lonergan & Lonergan, 2005; Celik & Yalmiz, 2010). The ash content is determined by burning/ashing the sample of meat (2.5 g) for 6 hours at 500ºC (AOAC, 2002, Method 942.05).

2.6 Common feedlot diseases

Prevention is better than cure when it comes to health in a feedlot, inoculation and drenching of lambs before entering the feedlot is therefore of great importance. Lambs should be free of diseases such as lameness, pinkeye and scabby mouth. Internal parasites and external parasites should be removed by administering a broad spectrum vaccine and by drenching the lambs before they enter the feedlot (Brand, 1995). Problems, however, that can occur include amongst others, acidosis, enteroxemia, eye infection, diarrhoea, kidney stones (urinary calculi), copper poisoning, pneumonia and foot rot.

2.6.1 Acidosis

Acidosis, also known as grain poisoning, is caused by a sudden change from a roughage based diet to a diet rich in carbohydrates (Duddy, 2007; Tarr, 1998; 2004). It leads to a rapid increase in gram positive bacteria (*Streptococcus bovis*) in the rumen (Slusser, 2008). The fermentation products of the bacteria cause a drop in the pH in the rumen when the lambs are fed starch-rich grains and pellets (Brand, 1995; Duddy, 2005). When the rumen pH reaches 5.2-5.8 the lambs discontinue eating (Jordan, 1990). Therefore, if the lambs are not properly adjusted to the rations the high starch level will lead to an increase in acidic rumen fluids and lactic acid production (Duddy, 2005; Slusser, 2008; Smith, 2011). The sudden increase in lactic acid production will cause inflammation of the rumen and a decrease in pH. Eventually the low pH level leads to a decrease in blood supply which eventually again leads to renal failure.

Acidosis is more likely to occur with a sudden change of grain in the diet, an increased grain intake or when lambs are introduced to grain for the first time (Duddy, 2007; Slusser, 2008). Acidosis can be prevented by proper adaptation to rations and including a buffer (e.g. limestone, bentonite) in the diet (Brand, 1995; Oberem *et al*., 2006). Arching of the back, abdominal pain, bloated or dehydration are common symptoms of acidosis (Duddy, 2007; Slusser, 2008).

2.6.2 Urinary calculi (Bladder stones)

As previously stated, the primary objective of sheep in a feedlot is maximum gain, thus the need to feed the lambs high concentrate diets, however these diets could cause an imbalance between calcium (Ca) and phosphorus (P), which in turn can result in the formation of bladder stones (a high intake of phosphate leads to a Ca:P imbalance; Duddy, 2005; 2007; Jordan, 1990; Smith, 2011; Tarr, 1998; 2004). Usually grain has very low calcium (0.5%) concentrations. Urinary calculi commonly occur in rams and drylot wethers (Brand, 1995; Chiba, 2009). The proper recommended calcium:phosphorus ratio is 2:1 (Jordan, 1990). Feeding high concentrate and low roughage diets will also increase incidences of kidney stones.

Phosphate is normally recycled by the saliva and eventually excreted via the faeces; a low roughage diet will result in less saliva production and an increase in the amount of phosphate that has to be excreted via the kidneys. Phosphates will thus accumulate in the kidney and result in the formation of the stones, blocking the urinary tract; eventually the bladder will burst resulting in death (Duddy, 2007; Slusser, 2008).

Salts and limestone can be used as additives in the diet to balance calcium and phosphorus. Another benefit from using salt as an additive to prevent bladder stone formation is that salt increases water intake which in turn leads to the flushing of the urinary tract (Duddy, 2005). The amount of roughage in the ration can also be increased or 0.5-1% ammonium chloride or 0.5-0.8% ammonium sulphate can be added to the diet to prevent the formation of kidney stones (Oberem *et al*., 2006).

2.6.3 Eye disorders

Eye infection is an infectious and irritating disease that will lead to a reduction in feed intake and therefore growth of feedlot lambs. It is especially a problem in dusty fly ridden feedlots with a high density of animals.

Vitamin A deficiencies could also cause eye disorders especially under close contact situations typically found in a feedlot situation (Duddy, 2005). Affected animals need to be moved to a shady, dust free area. Treatment is only recommended when both eyes are affected since the infection usually runs its course in a week (Duddy, 2005). It is suggested that management try to prevent eye infection by managing fly strikes; this can be done by removing faeces regularly and keeping the lot as dry as possible, especially around the water troughs.

2.6.4 Enteroxemia

Enteroxemia, also known as pulpy kidney or overeating disease, is a clostridial disease responsible for a large number of deaths in the small stock industry, especially feedlot lambs (Jordan, 1990). Pulpy kidney is a result of a sudden increase in the carbohydrate fraction of a diet (Newsom & Cross, 1943; Brand, 1995). Lambs will die in the first few days after they received the new diet without showing any symptoms.

Clostridium perfringens, type D, thrives on sugars and starches. These components are digested in the upper portion of the digestive tract. *Clostridium perfringens* type D produce toxins which causes enteroxemia, which is the most common nutrition related problem

(Chiba, 2009; Jordan, 1990; Smith, 2011; Tarr, 2004). Fast-gaining, larger lambs are more prone to be affected by enteroxemia; when these lambs overeat, not all the carbohydrates are utilized and therefore some are passed on to the lower digestive tract. This allows the *Clostridium perfringens* to grow excessively and produce lethal amounts of toxin that are absorbed into the animal's system. The most efficient manner of preventing pulpy kidney is by vaccinating the lambs when they are weaned and again after three to four weeks (Oberem *et al*., 2006).

2.6.5 Diarrhoea

Diarrhoea in a feedlot is usually due to overfeeding of concentrate or bad adaptation of animals to a high concentrate diet. Lambs will stop eating and growth will come to a standstill, it is best to remove these sheep from the feedlot, give them a dose of "rumagest antiacid" (or a similar compound) and put them on a high roughage diet until they are well (Oberem *et al*., 2006).

2.6.6 Copper poisoning

Copper poisoning is due to a high copper concentration in feed, usually when chicken faeces are used. Inclusion levels of copper higher than 10 ppm are toxic to lambs (Brand, 1995). High concentrations of Cu will lead to abdominal pain and death after 12 hours. Poisoning can be treated by administering 100 mg ammonium- or sodium molybdenite plus 1g of sodium sulphate per sheep/day for 10 days.

2.6.7 Foot rot

Foot rot is causes by *Fusobacterium necrophorum* and *Bacteroides nodosus* and is spread by carrier animals (Jordan, 1990). According to Oberem *et al*. (2006), wool breeds such as Merino's are more prone to foot rot than meat breeds. Foot rot is especially a problem during times of high rainfall in badly drained feedlots. The wet muddy conditions will soften the foot, making it more prone for infection. Infected animals must be isolated as fast as possible, placed in a dry camp and receive a daily foot bath in a 10% zinc-sulphate solution (Oberem *et al*., 2006).

2.6.8 Indigestion

Indigestion is a common feedlot disease when lambs are started on grain (Newsom & Cross, 1943). The lambs need to be gradually introduced to the grain diet so as to over-come this problem.

2.6.9 Liver abscesses

Liver abscesses are a result of too little roughages included in the diet of the feedlot lamb (Brand, 1995). This can be prevented with the inclusion of tylosin phosphate or tylosin urea adduct in the diet of the lamb (Brand, 1995; Brown *et al*. 1973). Feeds containing urea may not be exposed to rain, because the urea in the feed will dissolve in the water which leads to intake levels exceeding 2% (Brand, 1995).

2.6.10 Poisoning

When using growth stimulants and/or ionophores it is crucial to include it into the diets at the exact inclusion levels (Brand, 1995), if not it could be toxic to the lamb. Urea is another crucial ingredient in the diet and should not exceed the inclusion level of 2% of the diet (Brand, 1995).

2.7 Conclusions

Energy is the largest proportion of a diet and is more frequently, than any other nutrient, the first limiting nutrient in diets, this associated with the fact that feed costs are the largest cost associated with a feedlot it is detrimental to supply growing lambs with the optimal energy level. Inadequate energy levels (under- or over feeding) manifest itself in reduced growth, weight loss, reduced quality and quantity of wool, lowered resistance to infections and diseases and increased mortalities. Therefore it is of great importance to supply the lamb with adequate dietary energy levels which would satisfy their requirements.

As little is known on the use of β-AA (zilpaterol hydrochloride) on sheep in particular, as pertaining to the production and meat quality, different levels of energy will be fed to South African Mutton Merino lambs with either the inclusion or absence of ZH in the diet.

The subsequent trials will be used to determine the effect of dietary energy level, β-AA and gender on the various production and meat quality characteristic parameters.

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CHAPTER 3

THE EFFECT OF DIETARY ENERGY AND THE USE OF A β-AGONIST ON THE PRODUCTION AND CARCASS YIELD OF SOUTH AFRICAN MUTTON MERINOS UNDER FEEDLOT CONDITIONS*

*Partly published as: Effects of dietary energy content and provision of β-adrenergic agonist on the production of feedlot lambs. T.S. Brand, M.P. Genis, L.C. Hoffman, W.F.J. van de Vyver & G.F. Jordaan. (2013). *South African Journal of Animal Science*, 43, 5, S135 – S139.

ABSTRACT

Recent (2011-2012) increases in mutton and lamb prices in South Africa have resulted in many lamb producers opting to finish an increasing number of lambs in a feedlot system rather than marketing directly from the field. The aim of this trial was to determine the effect of dietary energy levels as well as the inclusion of a β-adrenergic agonist on the production of feedlot lambs. South African Mutton Merino lambs of different sexes were weaned at *ca.* 120 days of age and were randomly divided into six experimental groups (experiment 1, 108 lambs) and three experimental groups (experiment 2, 120 lambs), with each group receiving a different treatment combinations. Lambs were housed in individual pens. Both experiments consisted of three diets (diet 1 – 11.3 MJ ME/kg feed, diet 2 – 12.0 MJ ME/kg feed and diet 3 – 12.7 MJ ME/kg feed) with either the inclusion or absence of a β-adrenergic agonist (only included in experiment 1) at a concentration of 8.6 g/ton. The experimental design was a 3 (dietary energy level) x 2 (β-AA) x 2 (gender; experiment 1) and a 3 (dietary energy level) x 2 (gender; experiment 2) factorial design respectively. Dietary energy level only affected the dressing percentage in the first experiment, while it affected several parameters in the second experiment. The lambs on the low dietary energy level had a significantly lower dressing percentage (44.6 ± 0.41) compared to the medium and high dietary energy lambs (44.0 ± 0.42 and 45.9 ± 0.42 respectively; Exp 1). The β-adrenergic agonist had no significant ($P>0.05$) effect on any of the parameters. Gender significantly ($P<0.05$) affect several of the production and carcass yield parameters in both experiments. In the first experiment the rams utilized their feed better with a consequently significantly higher ADG than the ewes (321.5 ± 9.57 vs. 254.4 ± 10.47), while no significant difference for FCR was noted between the

wethers and ewes in the second experiment, the wethers however did had a significantly higher ADG than the ewes (231.1 ± 41.43 vs. 199 ± 38.64).

3.1 INTRODUCTION

Rapid changes in consumer preferences over the past few years, most specifically regarding the increased demand for leaner meat, have forced the sheep production industry to evaluate and adapt their production strategies and management principles in order to satisfy the consumer's needs. This predominantly involved a shift from extensive to intensive finishing of lambs in the slaughter lamb production line. Feed cost make up the largest proportion of the costs of a production system; the key focus is therefore to optimise the use of the nutrients present in the feed. Either the under- or oversupply of nutrients in the feed will negatively influence the profitability of the system.

Before formulating a diet for livestock it is imperative to know which nutrients are provided by the different feeds available. One of the challenges currently being faced is the formulation of an optimal feedlot ration for lambs, especially with regard to the energy level of the diet. The rumen of the sheep is the first major site for digestion (Yilldiz *et al*., 2011), making the substrates available for fermentation and the influence thereof on the rumen pH important to consider when mixing and manipulating the nutrients in a feed.

The recent increase in mutton and lamb meat prices has resulted in many lamb producers opting to finish an increasing number of lambs on the farm in a feedlot system, rather than marketing them directly from the veld (natural grazing). Sheep abattoirs have also become more vertically integrated in the production system, buying in young weaned lambs and finishing them off in their own feedlot – which is often located adjacent to the abattoir.

The success of the small stock production industry is however dependent on consumer acceptability and the quality perception of consumers (Hoffman *et al*., 2003). The acceptability of the meat for the consumer is dependent on its toughness (chewiness and resistance), flavour and succulence (juiciness) (Hoffman *et al*., 2003). According to Notter *et al*. (1991) the carcass evaluation will eventually determine the type of production system that will satisfy the demand of the consumer. In recent years a great deal of effort by both the production and marketing sectors of the industry has been put into enlarging the mutton and lamb market while still supplying good quality meat to the consumer (Costa *et al*., 2010).

The most common production system practised in South Africa is the early weaning of lambs followed by finishing them off, either on pastures or in a feedlot, before slaughter. A feedlot is defined as an animal feeding operation, arranged in pens, used for fattening livestock prior to slaughter (Smith, 2011). The primary objective of feedlotting is to maximize the weight gain of lambs and to get them market-ready as soon as possible; however it is important to ensure consumer satisfaction and confidence in your product (Duddy, 2007; Hopkins & Fogarty, 1998; Slusser, 2008).

Beta-adrenergic agonists (β-AA, anabolic agents) are another method, in addition to nutrition and selection, used to enhance the growth efficiency of livestock (Fiems, 1987) although little research has been conducted on the use thereof in mutton production. β-AA are typically administrated orally through the diet. Commonly the administration of β-AA increases the average daily gain (ADG) and improves feed efficiency (Eckermann *et al*., 2011; Mersmann, 2002; Montgomery *et al*., 2009), decreases the deposition of adipose tissue and increases skeletal muscle (Lopez-Carlos *et al*., 2010; Mersmann, 1998). With the use of a β-AA muscle mass can be increased by up to 40% (Beermann, 1993; Mermann 1998), although the weight increase has been found to vary from muscle to muscle (Beermann, 2002). Avendano-Reyes *et al*. (2006) found that the use of Zilpaterol hydrochloride (ZH) increased the dressing percentage.

The aim of this study was to investigate the effect of different dietary energy levels and the provision of a β-AA (specifically ZH) on feedlot production and carcass yield of South African Mutton Merino (SAMM) lambs. The effect of gender was also investigated as a main contributing factor.

3.2 MATERIALS AND METHODS

3.2.1 Animals and sampling

This trial was done in two separate experiments. In the first experiment the animals received the three different dietary energy levels with or without a β-AA and in the second experiment only the effect of the three different dietary energy levels was tested. Diet 1 had a low dietary energy level (11.3 ME MJ/kg), diet 2 a medium energy level (12.0 ME MJ/kg) and diet 3 a high energy level (12.7 ME MJ/kg; Table 3.1). In the first experiment the animals were fed a restricted diet and in the second experiment the animals were fed *ad libitum*.

Table 3.1 The formulation of the diets fed to SAMM lambs in both Experiment 1 and 2

Ingredients	Diet composition % (As Is)		
	LE	**ME**	**HE**
Corn	44.30	54.90	65.50
Lucerne	40.00	25.90	11.80
Cottonseed oilcake	8.00	11.45	14.89
Molasses powder	2.50	2.50	2.50
Salt (NaCl)	1.00	1.00	1.00
Bicarbonate of Soda	1.00	1.00	1.00
Ammonium chloride	1.00	1.00	1.00
Limestone	0.90	1.10	1.30
Urea	0.50	0.50	0.50
Mono Calcium Phosphate	0.34	0.18	0.02
Vitamin & Mineral Premix	0.25	0.25	0.25
Sulphur	0.20	0.20	0.20
Growth promoters & Ionophores (Stafax, Tauratec & Thylan)	0.02	0.02	0.02
Total	**100**	**100**	**100**

LE – Low energy diet. ME – Medium energy diet. HE – High energy diet

Table 3.2 Nutrient composition (as-fed basis) and *in vitro organic material digestibility* (IVOMD) of the diets used in the two experiments

Nutrient	Experiment 1			Experiment 2		
	LE	**ME**	**HE**	**LE**	**ME**	**HE**
Dry matter, %	87.34	87.11	87.55	89.78	89.88	88.85
Crude Protein, %	13.90	13.40	13.44	13.34	13.43	14.09
Ash, %	6.07	4.81	3.85	8.71	7.48	6.37
Fat, %	3.06	3.28	3.67	2.13	2.28	2.48
Crude Fibre, %	6.19	4.20	1.44	13.80	10.30	7.30
Calcium, %	0.77	0.71	0.65	1.22	1.14	1.08
Phosphorus, %	0.89	0.85	0.80	0.37	0.41	0.43
IVOMD, %	78.36	83.13	86.13	78.36	83.13	86.13

LE – Low energy diet. ME – Medium energy diet. HE – High energy diet.

In the rumen acidosis could be a problem when high energy diets, typically as used in feedlots, are fed to sheep. Therefore it was deemed necessary to evaluate the effect of the experimental diets on the rumen pH. Three ruminally cannulated sheep were used to determine the effect of the diet on the rumen pH. All three sheep received all three diets with three periods. Each period consisted of 5 days collection period with no prior adaptation period. Each fistulised sheep received each of the three trial diets (Table 3.3).

Table 3.3 Experimental layout

	Fistulised Sheep 1	Fistulised Sheep 2	Fistulised Sheep 3
Period 1	LE	ME	HE
Period 2	ME	HE	LE
Period 3	HE	LE	ME

LE – low energy diet, ME – medium energy diet, HE – high energy diet

The pH meter was calibrated each morning before data collection commenced. After an initial, fasted pH had been taken the sheep were fed the specific experimental diet assigned to them and the pH was then recorded hourly for a period of five hours. The first reading, reading 0, was before the lambs were fed anything, thereafter the pH was recorded hourly (reading 1, 2, 3, 4, 5).

Experiment 1:

One hundred and eight SAMM lambs (Figure 3.1) of different sexes were obtained from Langgewens Experimental Farm, Western Cape, South Africa. These lambs were weaned at *ca.* 120 days of age. The lambs were transported from Langgewens to the experimental site, Elsenburg Experimental Farm, Western Cape, South Africa. On arrival the lambs were randomly allocated into six groups (18 lambs/group equal number of rams and ewes/group; Figure 3.1) and vaccinated against pulpy kidney/enterotoxaemia (withdrawal period of 21 days; OBP, 1947 under normal feedlot conditions). The lambs were housed in pens of a size (117 cm x 177 cm) within the norms described by animal welfare guidelines (SAFA, 2014).

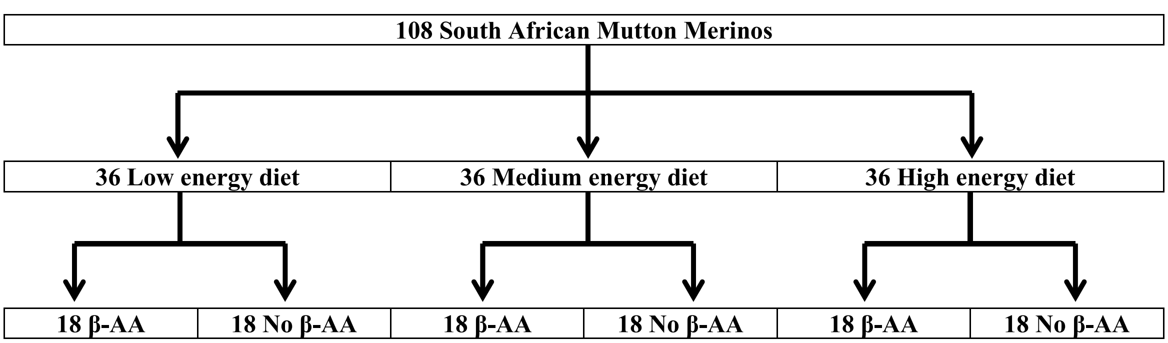

Figure 3.1 Schematic representation of Experiment 1

The treatments consisted of three different diets with varying dietary energy levels, formulated such that diet 1 was a low energy level diet (11.3 MJ ME/kg feed; LE), diet 2 was a medium energy level diet (12.0 MJ ME/kg feed; ME) and diet 3 was a high energy level diet (12.7 MJ ME/kg feed; HE), with each diet further either containing a β-AA or not, resulting in six treatment groups being defined. The particular β-AA used in this trial was Zilpaterol hydrochloride (ZH; commonly known as Zilmax; Intervet (Pty) Ltd., 20 Sparton Road, Kempton Park, 1619, South Africa), included in the diet at a rate of 8.6 g/ton (recommended by Intervet). The β-AA was withdrawn from the diet 3 days prior to slaughter (Shelver & Smith, 2006).

The lambs were provided with fresh clean water daily and were fed a restricted diet. Weekly weightings of both feed refusals and the lambs themselves were performed. The lambs were kept in the feedlot for approximately six weeks and sheared just prior to slaughter. The total wool weight (fleece weight) was determined and the quality of the wool was analysed (micro fibre diameter and comfort factor at the wool testing bureau in Port Elizabeth). The lambs were slaughtered at a greater weight (± 54 kg) than is normal for commercial feedlots (± 40-45 kg) in order to determine whether and how the use of a β-AA affected the carcass composition.

Twenty-four hours prior to slaughter the lambs were weighed; this weight was used as the final live weight of the lambs. The lambs were transported to a registered sheep abattoir (Roelcor, Malmesbury, Western Cape, South Africa), where they were slaughtered using standard South African techniques (Hoffman *et al*., 2003).

Experiment 2:

One hundred and twenty SAMM lambs (Figure 3.2) of different sexes were obtained from Langgewens Experimental Farm, Western Cape, South Africa. These lambs were weaned at *ca*. 120 days of age, with an average weight of 44.7 kg. The lambs were transported from Langgewens to the experimental site, Elsenburg Experimental Farm, Western Cape, South Africa. On arrival the lambs were randomly allocated to one of the three treatment groups (20 lambs/group equal number of wethers and ewes/group; Figure 3.2), and vaccinated against pulpy kidney/enterotoxaemia (withdrawal period of 21 days; OBP, 1947 under normal feedlot conditions). The lambs were housed in pens conforming to the norms (117 cm x 177 cm) described by animal welfare guidelines (SAFA, 2014).

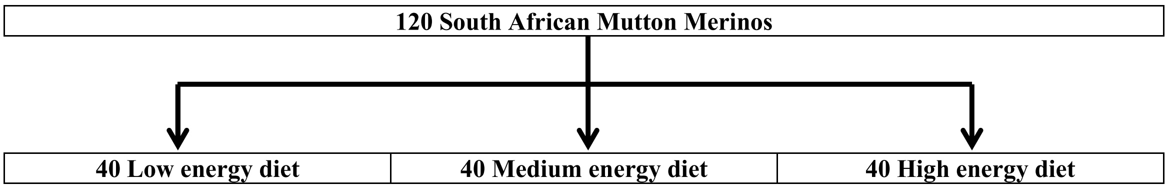

Figure 3.2 Schematic representation of trial 2

The treatments consisted of three diets with different dietary energy levels formulated such that diet 1 was a low energy level diet (11.3 MJ ME/kg feed; LE), diet 2 was a medium energy level diet (12.0 MJ ME/kg feed; ME) and diet 3 was a high energy level diet (12.7 MJ ME/kg feed; HE).

The lambs were provided with fresh clean water daily and were supplied with feed on an *ad libitum* basis. Feed refusals were weighed back daily while lambs were weighed once every fortnight. The lambs were kept in the feedlot for approximately 6 weeks and were sheared just prior to slaughter. The total wool (fleece weight) sheared from each lamb was weighted and a quality (micro fibre diameter, comfort factor and crimp length) analysis was performed on the wool.

The lambs were kept in the feedlot for the same timespan as the lambs in Experiment 1. They were weighed twenty-four hours prior to slaughter, with this weight being used as the final live weight of the lambs. The lambs were slaughtered using standard South African techniques in the same registered sheep abattoir used for lambs in Experiment 1 (Roelcor, Malmesbury, Western Cape, South Africa). No electrical stimulation was applied.

3.2.2 Instrumental analyses

In both experiments, the same muscle pH and temperature measurements were taken. The pH of the carcasses was measured 45 minutes after slaughter and just prior to the carcasses being placed in the cooling unit (5°C) for 48 hours. Prior upon entering the cooling unit the various fat depots (heart, kidney and visceral fat) were collected and weighted. The pH meter was calibrated before measurement of the pH began as well as after every 10^{th} reading, with the probe being rinsed with distilled water between each measurement. The pH meter contained a temperature probe which automatically adjusted the pH for the carcass temperature. The pH measurements were taken in the *m. longissimus dorsi* from between the 2^{nd} and 3^{rd} last thoracic vertebrae.

The chilled carcasses were weighed at approximately forty-eight hours post-mortem in order to determine the dressing percentage for each carcass. The ultimate pH and temperature for each carcass was also measured, with measurements being taken at the same position as those performed the day of slaughter.

3.2.3 Statistical analyses

The data of the pH measurements were analysed with a linear regression, where the slopes of the various diets were compared, using SAS for Windows Version 9.1.3 Proc. REG (SAS, 2000). Normality of the data was tested with the Shapiro-Wilk test (Shapiro & Wilk, 1965). Outliners were removed prior to the final analyses, which caused deviations from normality.

Experiment 1:

A linear regression analysis was performed on the rumen pH data set using SAS for Windows Version 9.1.3 Proc. REG, comparing the slopes for differences.

The experiment consisted of a completely randomised design with six treatments (three dietary energy levels with or without the inclusion of a β-AA). The treatment design was a 3 x 2 x 2 factorial with three dietary energy level (low, medium and high), the provision of a β-AA (either included or not) and gender (rams and ewes) as the main factors.

A factorial analysis of variance was performed on the data using SAS for Windows Version 9.1.3 Proc GLM (SAS, 2000), while normality was tested using the Shapiro-Wilk test (Shapiro & Wilk, 1965). Outliers causing deviations from normality were removed before the final analyses were performed. Student's t-Least Significant Differences (LSD) were calculated at the 5% significance level to compare treatment means. The ADG of the lambs was calculated using regression analysis.

Experiment 2

The experiment consisted of a completely randomised design with three treatments (three dietary energy level). The treatment design was a 3 x 2 factorial with dietary energy level (low, medium and high), and gender (wethers and ewes) as the main factors.

A factorial analysis of variance was performed on the data using SAS for Windows Version 9.1.3 (SAS, 2000), whereas normality was tested using the Shapiro-Wilk test (Shapiro & Wilk, 1965). Outliers which caused deviations from normality were removed before the final analyses were performed. The ADG of the lambs were calculated using regression analysis.

3.3 RESULTS

No significant difference in the rumen pH between the various dietary energy levels was found (Table 3.4) and the change in the rumen pH caused by the three experimental diets is depicted in Figure 3.3.

Table 3.4 Linear regression equations of the rumen pH as affected by the experimental diets

Rumen pH	Linear Regression Equation	R^2	P-Value
LE	y = -0.05x + 5.892	0.6035	0.389
ME	y = -0.01x + 5.9694	0.6057	0.389
HE	y = -0.064x + 5.9211	0.6028	0.389

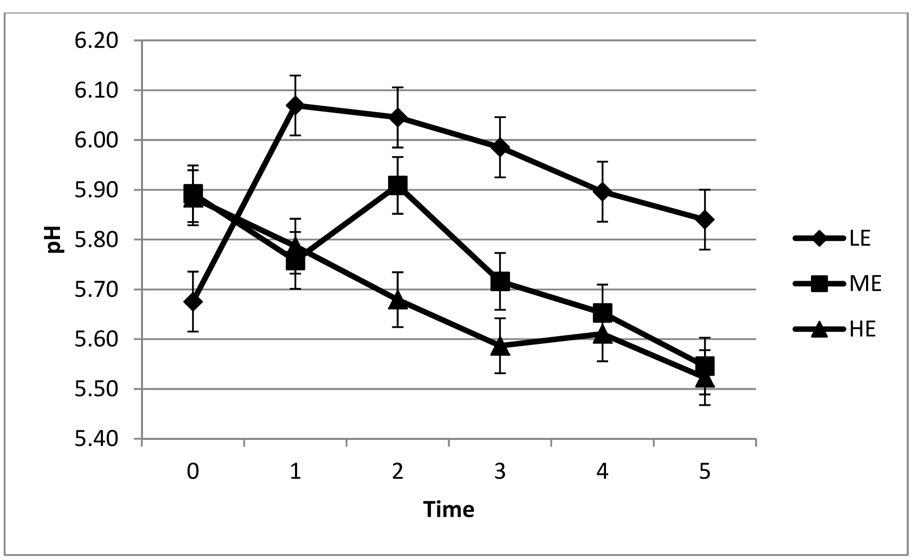

Figure 3.3 The change in rumen pH, as affected by the experimental diets

The changes in rumen pH over time for the ME and HE diets showed a similar downward trend, although there was an upward trend for the ME diet between time interval 1 and 3. The trend for all three diets showed a gradual decline in rumen pH from time interval 2 onwards, although ME only started decreasing after time point 3. However it was peculiar that the rumen pH increased when the lambs were fed the LE diet.

Experiment 1

Apart from for visceral fat, no interactions between the main effects (dietary energy level, β-AA and gender) were observed. This allowed the main effects to be interpreted individually for all the other measured traits. For visceral fat the main effects could not however be separately interpreted due to the aforementioned interaction.

None of the production (Table 3.5 – 3.8; Figure 3.4 – 3.6), wool (Table 3.6) or carcass yield parameters (Table 3.7) was affected by the energy treatment apart from the dressing percentage (Table 3.7).

Table 3.5 Least square means (± s.e.) depicting the effect of dietary energy content on the production parameters of SAMM lambs fed three diets with different dietary energy levels during experiment 1

Production Parameters	LE	ME	HE	P-Value
Starting weight (kg)	$38.0^{a} \pm 0.96$	$38.6^{a} \pm 0.96$	$37.1^{a} \pm 0.97$	0.559
Slaughter weight (kg)	$55.5^{a} \pm 1.01$	$54.6^{a} \pm 1.04$	$53.6^{a} \pm 1.02$	0.422
Total feed intake (kg)	$75.1^{a} \pm 0.84$	$76.1^{a} \pm 0.85$	$74.5^{a} \pm 0.86$	0.406
Feed intake (kg per day)	$1.9^{a} \pm 0.34$	$1.9^{a} \pm 0.33$	$1.9^{a} \pm 0.34$	0.263
FCR[#] (kg feed/kg weight gain)	$4.2^{a} \pm 0.22$	$4.3^{a} \pm 0.23$	$4.5^{a} \pm 0.23$	0.610
ADG (g)	$296.8^{a} \pm 11.84$	$289.5^{a} \pm 12.09$	$278.6^{a} \pm 12.20$	0.532

[a,b] Row means with different superscripts differ significantly ($P \leq 0.05$)

[#] feed conversion ratio, is the kg feed consumed/ kg weight gained

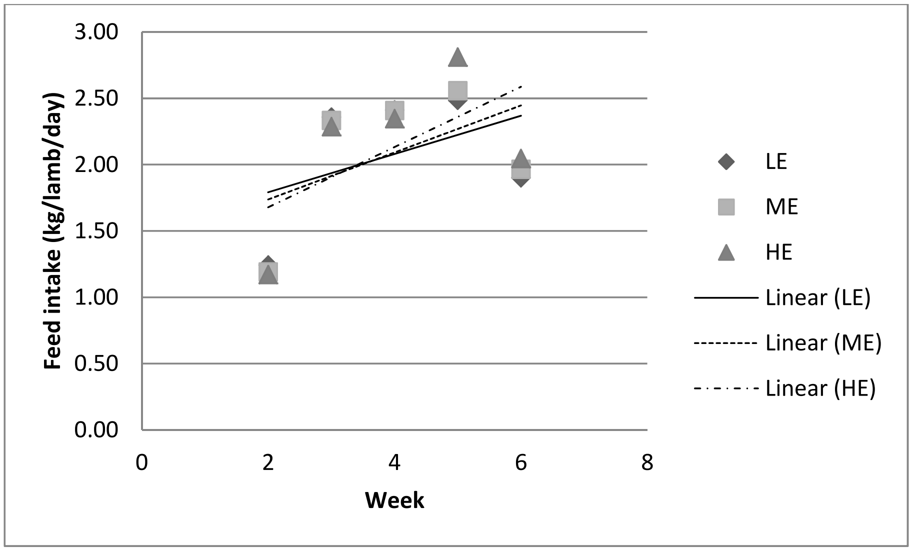

Figure 3.4 Linear regression of weekly feed intake as per dietary energy level of Experiment 1

A gradual positive incline in feed intake with an increase in age was noted for lambs on all three dietary energy levels.

Table 3.6 Linear regression equations of weekly feed intake (kg/lamb daily) over time of South African Mutton Merino lambs fed three different dietary energy levels

Diet	Linear regression equation	R^2
LE	y= 0.1444x + 1.5024	0.1922
ME	y = 0.1773x + 1.3882	0.2617
HE	y = 0.02272x + 1.2238	0.3535

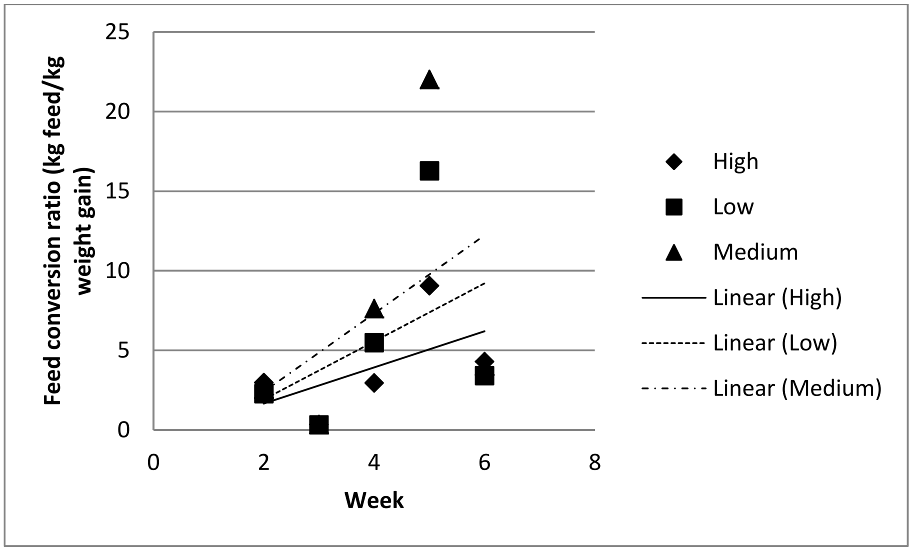

Figure 3.5 Linear regression of weekly feed conversion ratio's over time as per dietary energy level for Experiment 1

A gradual positive incline in the feed conversion ratio with age was noted for lambs receiving all three dietary energy levels.

Table 3.7 Linear regression equations of weekly feed (kg feed/kg weight gain) conversion ratio over time of South African Mutton Merino lambs fed three different dietary energy levels

Diet	Linear regression equation	R^2
LE	y = 1.823x – 1.732	0.2109
ME	y = 2.457x – 2.514	0.2023
HE	y = 1.137x – 0.620	0.3143

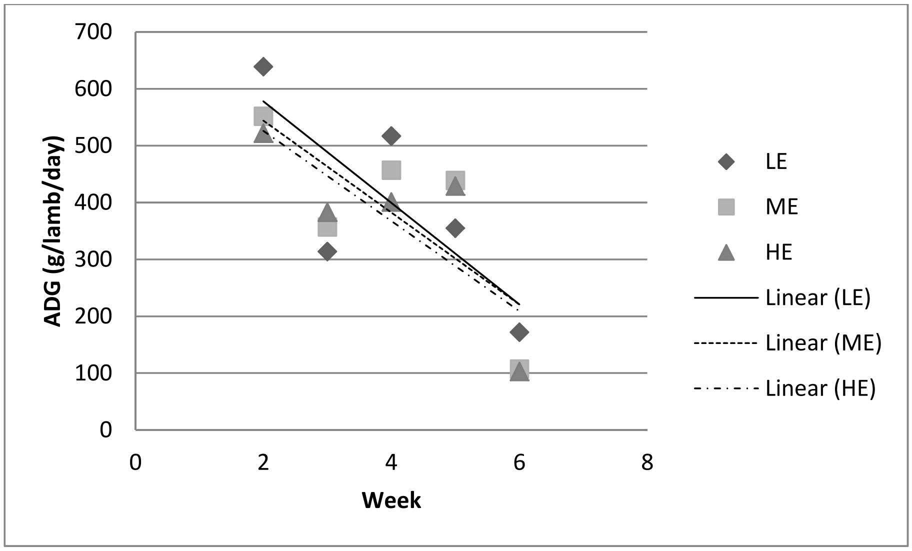

Figure 3.6 Linear regression of weekly weight gain over time as per dietary energy level for Experiment 1

A rapid decline in average daily weight gain was noted with an increase in age for lambs on all three dietary energy levels.

Table 3.8 Linear regression equations of weekly weight gain (g/lamb/day) over time of South African Mutton Merino lambs fed three different dietary energy levels for experiment 1

Diet	Linear regression equation	R^2
LE	y = -89.3x + 756.6	0.6032
ME	y = -80.8x + 705.6	0.5726
HE	y = -79.2x + 684.4	0.6338

Table 3.9 Least square means (± s.e.) depicting the effect of dietary energy level on wool production parameters of SAMM lambs fed three different dietary energy diets during experiment 1

Wool Parameters	LE	ME	HE	P-Value
Fleece weight (kg)	$1.59^a \pm 0.05$	$1.70^a \pm 0.05$	$1.61^a \pm 0.05$	0.364
Micro fibre diameter (µm)	$22.87^a \pm 0.23$	$23.26^a \pm 0.24$	$23.41^a \pm 0.24$	0.255
Comfort factor# (%)	$94.9^a \pm 0.72$	$94.0^a \pm 0.74$	$93.3^a \pm 0.73$	0.324

[a,b] Row means with different superscripts differ significantly ($P \leq 0.05$)

[#]The comfort factor is the percentage of fibres

Table 3.10 Least square means (± s.e.) depicting the effect of dietary energy content on carcass yield parameters of SAMM lambs fed three different dietary energy diets during experiment 1

Carcass Yield Parameters	LE	ME	HE	P-Value
Carcass weight (kg)	$25.6^{a} \pm 0.54$	$26.3^{a} \pm 0.55$	$25.2^{a} \pm 0.56$	0.402
Dressing percentage (%)	$44.6^{a} \pm 0.41$	$46.0^{b} \pm 0.42$	$45.9^{a,b} \pm 0.42$	0.033
Heart fat (%)	$0.3^{a} \pm 0.02$	$0.3^{a} \pm 0.02$	$0.3^{a} \pm 0.02$	0.253
Kidney fat (%)	$2.1^{a} \pm 0.16$	$1.9^{a} \pm 0.16$	$2.2^{a} \pm 0.16$	0.554
Visceral fat[#] (%)	2.0 ± 0.10	2.0 ± 0.10	2.3 ± 0.11	0.050

[a,b] Row means with different superscripts differ significantly ($P \leq 0.05$)

[#]Due to interaction main effects cannot be interpreted

Contrary to expectations, the results indicated that the lambs fed the medium dietary energy level (46.0 ± 0.42) rather than the highest energy level (45.9 ± 0.42) had the highest dressing percentage. It must be noted however that the difference in dressing percentage between these two treatment groups was not statistically significant (Table 3.10).

None of the production, wool or carcass yield parameters was affected by the presence or absence of the β-AA in the diet. Refer to Tables 3.11 – 3.16 and Figures 3.7 – 3.9 for the effect of the β-AA on the production, wool and carcass yield parameters.

Table 3.11 Least square means (± s.e.) depicting the effect of the β-AA on the production parameters of SAMM lambs during Experiment 1

Production Parameters	β-AA		
	Absent	Included	P-Value
Starting weight (kg)	$37.4^{a} \pm 0.78$	$38.5^{a} \pm 0.79$	0.357
Slaughter weight (kg)	$54.0^{a} \pm 0.83$	$55.2^{a} \pm 0.83$	0.290
Total feed intake (kg)	$76.0^{a} \pm 0.69$	$74.5^{a} \pm 0.70$	0.130
Feed intake (kg per day)	$1.9^{a} \pm 0.22$	$2.0^{a} \pm 0.23$	0.478
FCR (kg feed/kg weight gain)	$4.3^{a} \pm 0.18$	$4.3^{a} \pm 0.18$	0.898
ADG (g)	$286.2^{a} \pm 9.81$	$289.6^{a} \pm 9.89$	0.810

[a,b] Row means with different superscripts differ significantly ($P \leq 0.05$)

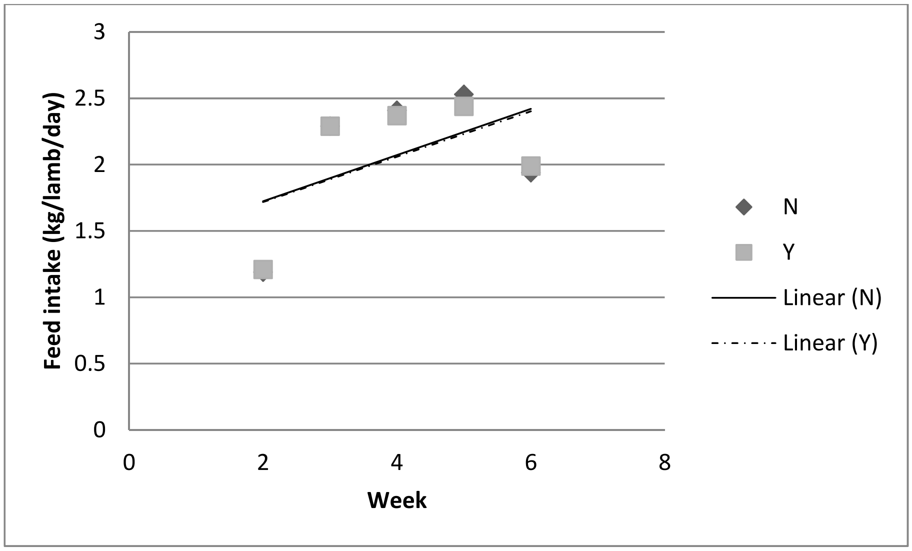

Figure 3.7 Linear regression of weekly feed intake over time as per β-AA treatment for Experiment 1 (N – β-AA absent; Y – β-included)

A gradual positive incline in feed intake with an increase in age was observed for both the β-AA included and absent groups.

Table 3.12 Linear regression equations of weekly feed intake (kg/lamb/day) over time of SAMM lambs either receiving or not receiving the β-AA in Experiment 1

β-AA	Linear regression equation	R^2
Absent	y = 0.174x + 1.376	0.2595
Included	y = 0.171x + 1.376	0.2865

Table 3.13 Linear regression equations of feed conversion ratios over time of SAMM lambs either receiving or not receiving β-AA in Experiment 1

β-AA	Linear regression equation	R^2
Absent	y = 1.9326x – 0.1202	0.6763
Included	y = 1.5415x + 0.3858	0.6109

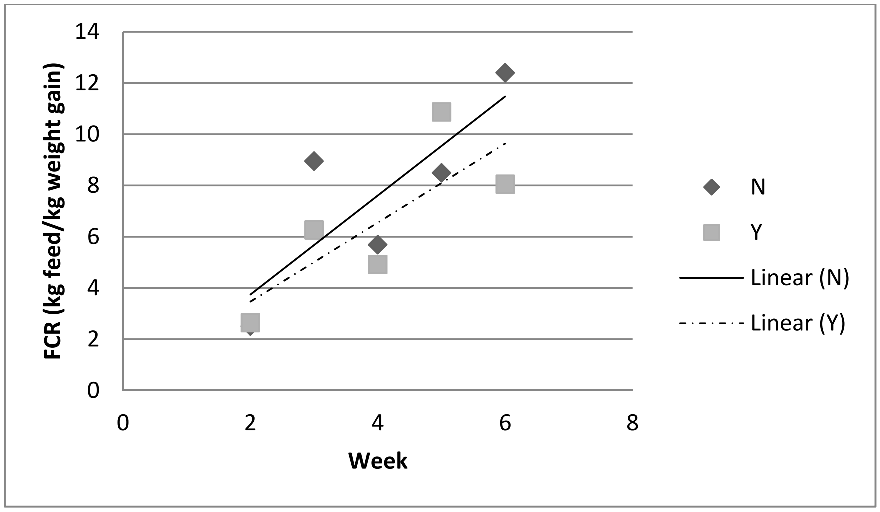

Figure 3.8 Linear regression of weekly feed conversion ratio over time as per β-AA treatment in Experiment 1

A strong positive incline in feed conversion ratio (kg feed/kg weight gain) with age was observed for the lambs of both treatment groups.

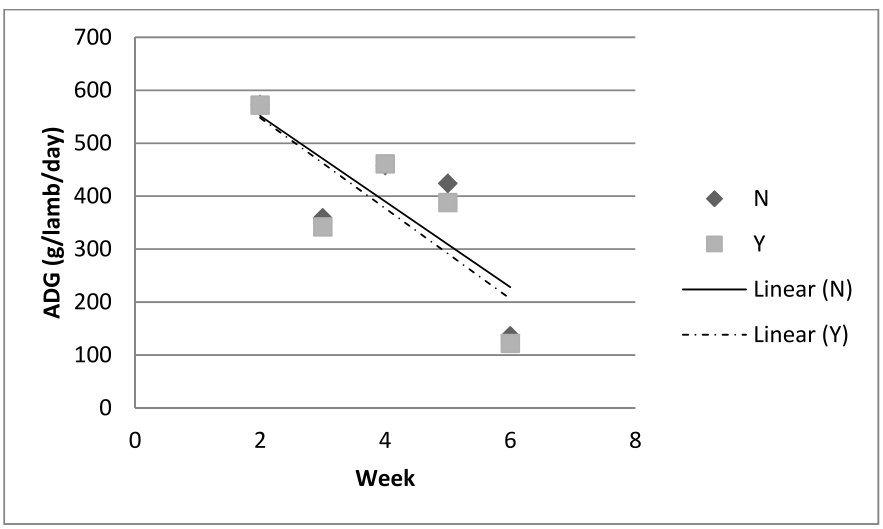

Figure 3.9 Linear regression of average daily weight gain over time as per β-AA treatment of Experiment 1 (N – β-AA absent; - β-AA included)

A rapid decline in weight gain with an increase in age was observed for the lambs of both treatment groups.

Table 3.14 Linear regression equations of average daily weight gain (g/lamb/day) over time of SAMM lambs either receiving or not receiving the β-AA in Experiment 1

β-AA	Linear regression equation	R^2
Absent	y = -80.9x + 713.6	0.6248
Included	y = -85.4x + 718.6	0.6544

Table 3.15 Least square means ± s.e. depicting the effect of β-AA on wool production parameters of SAMM lambs during Experiment 1

Wool Parameters	β-AA		
	Absent	Included	P-Value
Fleece weight (kg)	$1.66^a \pm 0.04$	$1.61^a \pm 0.04$	0.449
Micro fibre diameter (µm)	$23.19^a \pm 0.19$	$23.17^a \pm 0.19$	0.938
Comfort factor (%)	$94.0^a \pm 0.59$	$94.1^a \pm 0.60$	0.887

[a,b] Row means with different superscripts differ significantly ($P \leq 0.05$)

Table 3.16 Least square means (± s.e.) depicting the effect of β-AA on carcass yield parameters of SAMM lambs during Experiment 1

Carcass Yield Parameters	β-AA		
	Absent	Included	P-Value
Carcass weight (kg)	$25.5^a \pm 0.45$	$26.1^a \pm 0.45$	0.183
Dressing percentage (%)	$45.1^a \pm 0.34$	$45.9^a \pm 0.34$	0.079
Heart fat (%)	$0.3^a \pm 0.02$	$0.3^a \pm 0.02$	0.569
Kidney fat (%)	$2.1^a \pm 0.13$	$2.1^a \pm 0.13$	0.951
Visceral fat[#] (%)	2.0 ± 0.08	2.1 ± 0.08	0.171

[a,b] Row means with different superscripts differ significantly ($P \leq 0.05$)

[#]Due to interaction main effects cannot be interpreted

The following production and carcass yield parameters were affected by gender: FCR, ADG, slaughter weight, carcass weight and kidney fat. Refer to Tables 3.17 – 3.23 and Figures 3.10 – 3.12 for the effect of gender on these parameters.

Table 3.17 Least square means (± s.e.) depicting the effect of gender on the production parameters of SAMM lambs during Experiment 1

Production Parameters	Gender		
	Ewe	Ram	P-Value
Starting weight (kg)	$37.0^{a} \pm 0.81$	$38.9^{a} \pm 0.76$	0.079
Slaughter weight (kg)	$51.4^{a} \pm 0.88$	$57.8^{b} \pm 0.80$	<0.0001
Total feed intake (kg)	$75.9^{a} \pm 0.72$	$74.5^{a} \pm 0.64$	0.621
Feed intake (kg per day)	$1.9^{a} \pm 0.32$	$1.9^{a} \pm 0.32$	0.723
FCR (kg feed/kg weight gain)	$4.7^{a} \pm 0.19$	$3.9^{b} \pm 0.18$	0.019
ADG (g)	$254.4^{a} \pm 10.47$	$321.5^{b} \pm 9.57$	<0.0001

[a,b] Row means with different superscripts differ significantly ($P \leq 0.05$)

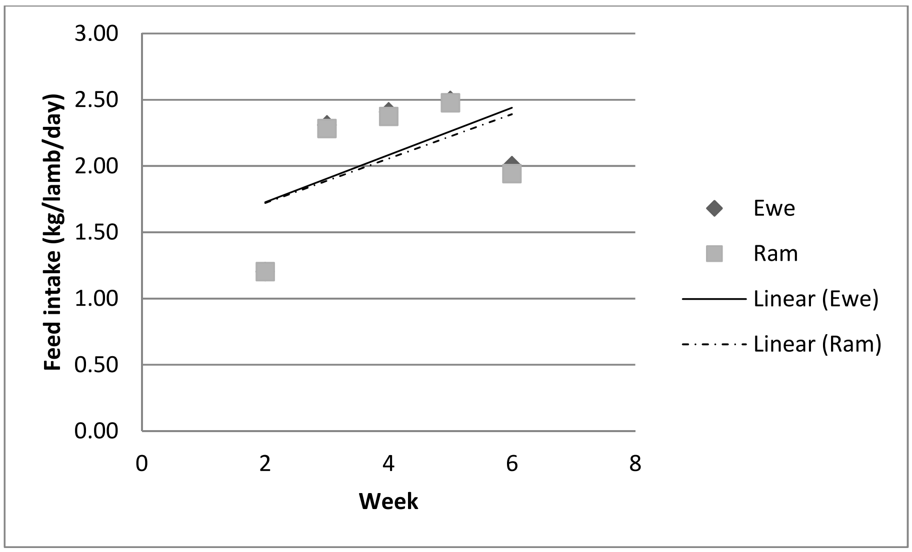

Figure 3.10 Linear regression of feed intake over time as per gender in Experiment 1

A gradual positive incline in feed intake with an increase in age was noted for lambs of both genders.

Table 3.18 Linear regression equations of weekly feed intake (kg/lamb/day) of SAMM lambs for Experiment 1

Gender	Linear regression equation	R^2
Ewe	$y = 0.1782x + 1.3706$	0.2868
Ram	$y = 0.1673x + 1.3870$	0.2614

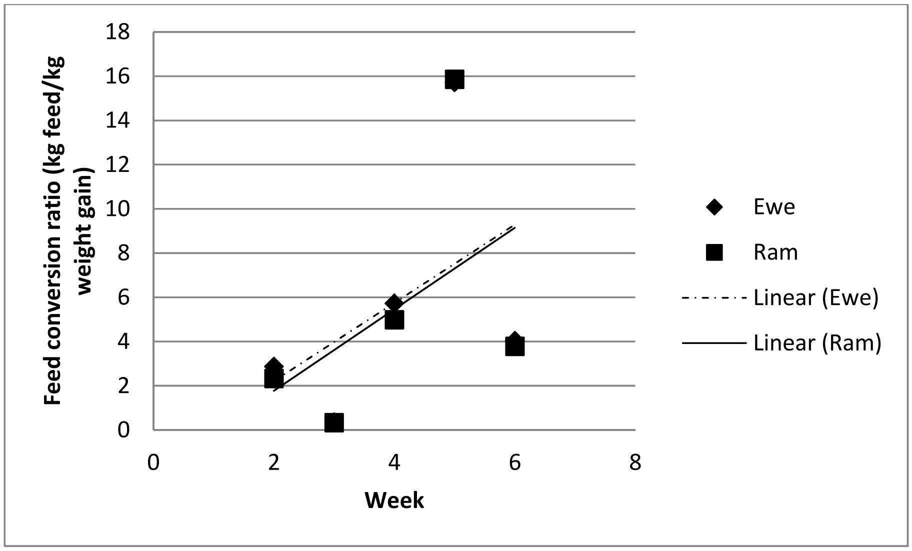

Figure 3.11 Linear regression of weekly feed conversion ratio as per gender for Experiment 1

A gradual positive incline in feed conversion ratio with an increase in age was noted in lambs of both genders.

Table 3.19 Linear regression equations of weekly feed conversion ratio (kg feed/kg weight gain) of SAMM lambs in Experiment 1

Gender	Linear regression equation	R^2
Ewe	y = 1.843x – 1.914	0.2243
Ram	y = 1.77x – 1.336	0.2306

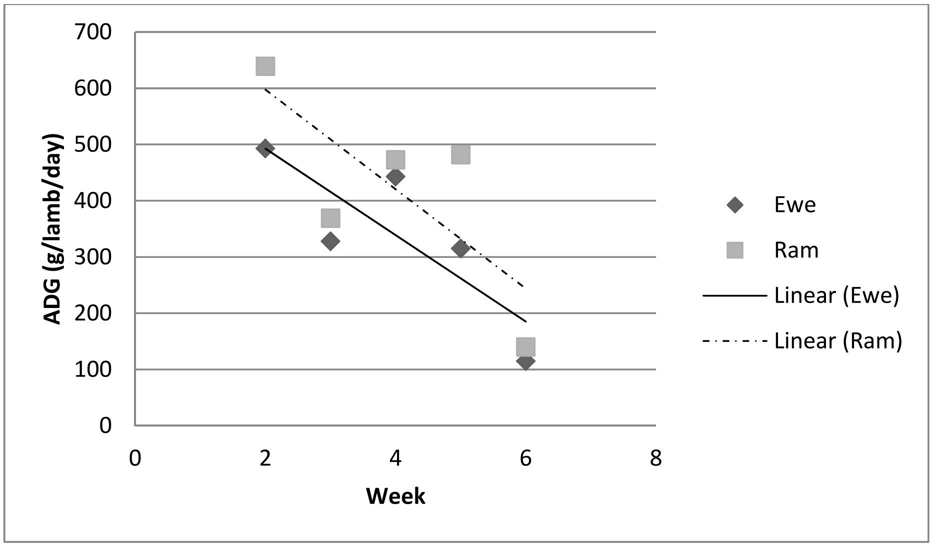

Figure 3.12 Linear regression of weekly weight gain, as per gender of Experiment 1

A rapid decline in the average daily weight gain with an increase in age was noted in lambs of both genders.

Table 3.20 Linear regression equations of weekly weight gain (g/lamb/day) of SAMM lambs in Experiment 1

Gender	Linear regression equation	R^2
Ewe	y = -76.9x + 646.4	0.6924
Ram	y = -88.5x + 774.6	0.5775

Table 3.21 Least square means (± s.e.) depicting the effect of gender on wool production parameters of SAMM lambs during Experiment 1

Wool Parameters	**Gender**		
	Ewe	**Ram**	**P-Value**
Fleece weight (kg)	$1.64^{a} \pm 0.05$	$1.63^{a} \pm 0.04$	0.851
Micro fibre diameter (µm)	$23.21^{a} \pm 0.20$	$23.15^{a} \pm 0.19$	0.822
Comfort factor (%)	$94.0^{a} \pm 0.62$	$94.04^{a} \pm 0.57$	0.984

^{a,b} Row means with different superscripts differ significantly ($P \leq 0.05$)

Table 3.22 Least square means (± s.e.) depicting the effect of gender on carcass yield parameters of SAMM lambs during Experiment 1

Carcass Yield Parameters	Gender		
	Ewe	Ram	P-Value
Carcass weight (kg)	$24.4^{a} \pm 0.47$	$26.9^{b} \pm 0.43$	0.0002
Dressing percentage (%)	$45.5^{a} \pm 0.36$	$45.5^{a} \pm 0.33$	0.966
Heart fat (%)	$0.3^{a} \pm 0.02$	$0.3^{a} \pm 0.02$	0.907
Kidney fat (%)	$2.5^{a} \pm 0.13$	$1.6^{b} \pm 0.13$	0.0003
Visceral fat[#] (%)	2.3 ± 0.09	1.8 ± 0.08	0.0002

[a,b] Row means with different superscripts differ significantly (P ≤ 0.05)

[#]Due to interaction main effects cannot be interpreted

Rams had both a higher slaughter (57.8 ± 0.80) and carcass weight (26.9 ± 0.43) than ewes (51.4 ± 0.88 and 24.4 ± 0.47 respectively). Ewes had a significantly higher percentage of kidney fat (2.5 ± 0.13) than their ram (1.8 ± 0.13) counterparts.

Of the measured parameters, only visceral fat showed an interaction between dietary energy level, β-AA and gender (Table 3.23). The main effects will therefore not be interpreted separately.

Table 3.23 Least square means (± s.e.) depicting the interaction of dietary energy, β-AA and gender on the measured parameter 'visceral fat' during Experiment 1

Parameters	Diet	β-AA	Gender	LSM ± SE
Visceral fat (%)	HE	N	F	$2.5^{b,c} \pm 0.20$
	LE	N	F	2.2 ± 0.23
	ME	N	F	1.7 ± 0.23
	HE	Y	F	$2.5^{b} \pm 0.19$
	LE	Y	F	2.5 ± 0.21
	ME	Y	F	2.4 ± 0.19
	HE	N	M	1.7 ± 0.20
	LE	N	M	1.7 ± 0.17
	ME	N	M	2.2 ± 0.17
	HE	Y	M	2.4 ± 0.26
	LE	Y	M	$1.6^{a,c} \pm 0.17$
	ME	Y	M	$1.5^{c} \pm 0.21$

[a,b] Column means with different superscripts differ significantly (P ≤ 0.05)

The rams who received diet 1 (low dietary energy) with β-AA included had a lower percentage visceral fat than the ewes who received diet 3 (high energy level) without the β-AA. Furthermore the ewes who received diet 3 (high energy diet) with the β-AA had a higher percentage visceral fat than the rams who received diet 1 (low energy diet) with the β-AA, while the ewes who received diet 3 (high energy level) with the β-AA had a higher percentage visceral fat than the rams on diet 2 (medium energy level) with β-AA.

Experiment 2

No interactions were observed between any of the main effects for any of the parameters measured in the second experiment, thus allowing the main effects to be interpreted separately. The production (Table 3.24 – 3.27 and Figures 3.13 – 3.15), wool (Table 3.28) and carcass yield (Table 3.29) parameters were influenced by the dietary energy level: feed intake, ADG, crimp length, slaughter weight and carcass weight.

Table 3.24 Least square means (± s.e.) depicting the effect of dietary energy content on the production parameters of SAMM lambs fed three different dietary energy levels during Experiment 2

Production Parameters	LE	ME	HE	P-Value
Starting weight (kg)	$45.4^{a} \pm 0.74$	$44.1^{a} \pm 0.74$	$44.8^{a} \pm 0.82$	0.454
Slaughter weight (kg)	$57.8^{a} \pm 0.92$	$54.9^{a,b} \pm 0.92$	$52.4^{b} \pm 1.03$	0.0007
Total feed intake (kg)	$56.5^{a} \pm 1.01$	$52.8^{b} \pm 1.02$	$41.6^{c} \pm 1.13$	<0.0001
Feed intake (kg per day)	$1.5^{a} \pm 0.03$	$1.4^{b} \pm 0.03$	$1.1^{c} \pm 0.03$	<0.0001
FCR (kg feed/kg weight gain)	$4.6^{a} \pm 0.21$	$5.2^{a} \pm 0.21$	$4.9^{a} \pm 0.25$	0.225
ADG (g)	$228.7^{a} \pm 47.36$	$213.6^{a,b} \pm 46.72$	$203.4^{b} \pm 55.62$	0.004

^{a,b,c} Row means with different superscripts differ significantly ($P \leq 0.05$)

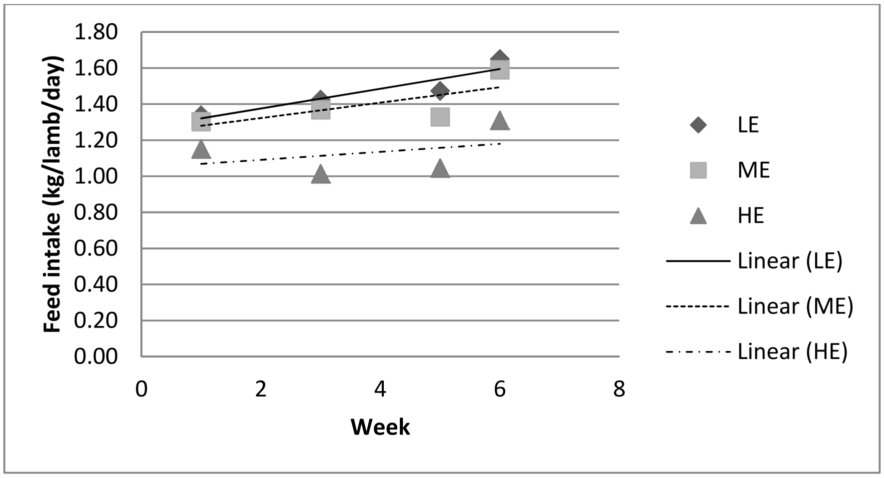

Figure 3.13 Linear regression of weekly feed intake (kg/lamb daily) as per dietary energy level in Experiment 2

A weak upward trend in feed intake is observed for the lambs on all three dietary energy levels.

Table 3.25 Linear regression equations of weekly feed intake (kg/lamb/day) of SAMM lambs on three different dietary energy levels in Experiment 2

Diet	Linear regression equation	R^2
LE	y = 0.0546x + 1.2667	0.8484
ME	y = 0.0427x + 1.2375	0.5212
HE	y =0.0223x + 1.0462	0.1363

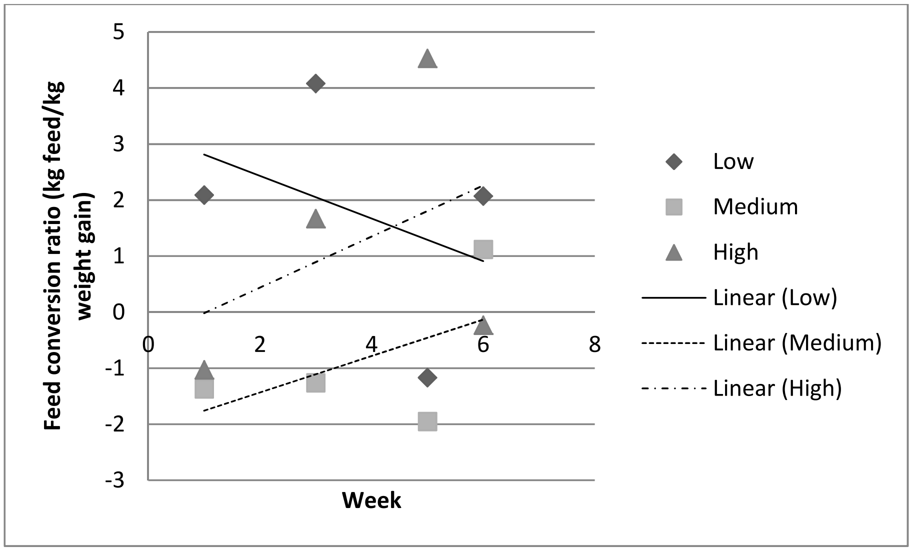

Figure 3.14 Linear regression of weekly feed conversion ratio (kg feed/kg weight gain) as per dietary energy of Experiment 2

A gradual decline with age in the feed conversion ratio of the lambs on the low energy diet was observed; while a gradual increase was observed in the feed conversion ratio of the lambs on both the medium and high energy diets.

Table 3.26 Linear regression equations of the weekly feed conversion ratio (kg feed/ kg weight gain) of SAMM lambs on three different dietary energy levels in Experiment 2

Diet	Linear regression equation	R^2
LE	y = -0.3805x + 3.1944	0.1507
ME	y = 0.3251x – 2.0841	0.282
HE	y = 0.4559x – 0.4747	0.1673

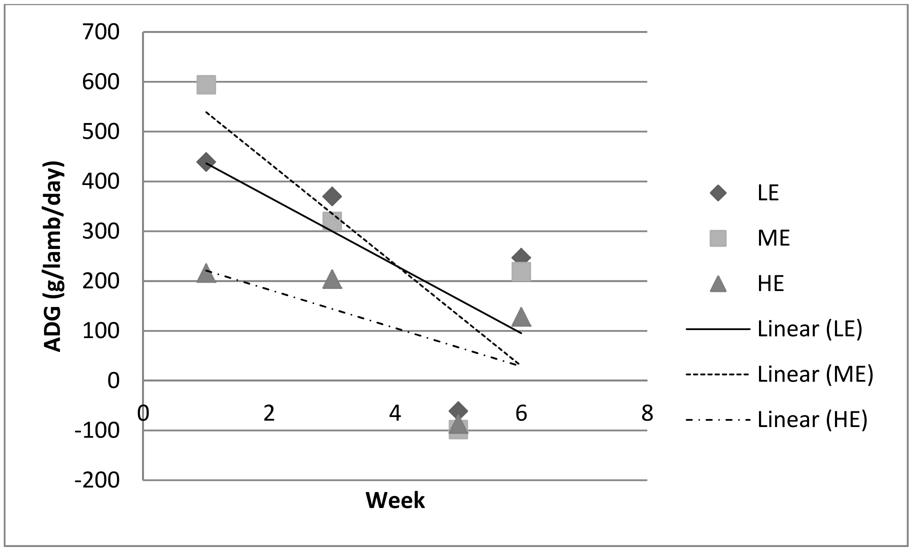

Figure 3.15 Linear regression of weekly weight gain (g/lamb daily) as per dietary energy in Experiment 2

A rapid downward trend is observed in the weight gain with age of the lambs on both the medium and low energy diet, while a more gradual decline is observed in the weight gain of the lambs on the high energy diet.

Table 3.27 Linear regression equations of the weekly feed conversion ratio (g/lamb/day) of SAMM lambs on three different dietary energy levels in Experiment 2

Diet	Linear regression equation	R^2
LE	y = -68.153x + 504.32	0.4665
ME	y = -101.92x + 640.93	0.6253
HE	y = -38.492x + 259.59	0.3698

Both the overall feed intake and the daily feed intake of all three dietary energy level diets differed significantly ($P<0.05$) from each other. The lambs receiving the low dietary energy level (56.47 ± 1.01; total and 1.53 ± 0.03; daily respectively) had the highest feed intake relative to the lambs who received the medium dietary energy level (52.82 ± 1.02; total and 1.43 ± 0.03; daily respectively) and those who received the high dietary energy level (41.60 ± 1.13; total and 1.12 ± 0.03; daily respectively).

All three of the diets used in Experiment 2 contained more than 10% CP (13.34%, 13.43 and 14.09% respectively) and less than 18.8% fibre (13.80%, 10.30% and 7.30% respectively).

The higher feed intake of the lambs fed the LE diet could be due to the lower energy density of the diet. This is in accordance with current literature. De Sousa *et al.* (2012) found that the feed intake of lambs who received a high energy level diet was inferior to that of lambs who received a low energy level diet. It therefore appears evident that an increase in the energy density of a diet leads to a decrease in feed intake as long as intake is not otherwise constricted by interfering factors (Hossain *et al*., 2003; Sayed, 2011).

The average daily gain of the lambs who received the low dietary energy level (228.71 ± 47.36) differed significantly (P<0.05) from that of the lambs who received the high dietary energy level (203.38 ± 55.62). Lambs on the low dietary energy level had the highest ADG relative to lambs on the medium and high dietary energy levels (213.63 ± 46.72). Jones *et al* (1973) found that increased dietary protein and energy levels increased both the ADG and feed efficiency. This is in contrast to findings of this experiment, where lambs on the low dietary energy level had a higher ADG. No significant differences in the FCR were found between the different treatment groups. The lambs on the LE diet had a higher total energy intake (Table 3.24), thus explaining their better growth and more favourable ADG and FCR values.

Table 3.28 Least square means (± s.e.) depicting the effect of dietary energy level on wool production parameters of SAMM lambs fed three different dietary energy diets during Experiment 2

Wool Parameters	LE	ME	HE	P-Value
Fleece weight (kg)	$1.68^{a} \pm 0.04$	$1.55^{a} \pm 0.04$	$1.60^{a} \pm 0.05$	0.132
Micro fibre diameter (µm)	$23.01^{a} \pm 0.23$	$22.44^{a} \pm 0.24$	$22.68^{a} \pm 0.26$	0.229
Comfort factor (%)	$95.1^{a} \pm 0.69$	$96.3^{a} \pm 0.71$	$96.4^{a} \pm 0.78$	0.352
Crimp length (mm)	$47.34^{a} \pm 0.91$	$46.71^{a} \pm 0.94$	$51.42^{b} \pm 1.04$	0.002

^{a,b} Row means with different superscripts differ significantly ($P \leq 0.05$)

The crimp length of the lambs on the high dietary energy level (51.42 ± 1.04) differed significantly from that of both the lambs on the low dietary energy level (47.34 ± 0.91) and those on the medium dietary energy level (46.71 ± 0.94). It did not however differ significantly between the lambs on the low and medium energy level diets. The crimp length of the lambs on the high dietary energy level was the highest relative to the lambs on the low and medium dietary energy levels.

Table 3.29 Least square means (± s.e.) depicting the effect of dietary energy content on carcass yield parameters of SAMM lambs fed three different dietary energy diets during Experiment 2

Carcass Yield Parameters	LE	ME	HE	P-Value
Carcass weight (kg)	$27.9^{a} \pm 0.52$	$26.9^{a,b} \pm 0.52$	$25.4^{b} \pm 0.58$	0.008
Dressing percentage (%)	$48.1^{a} \pm 0.36$	$49.0^{a} \pm 0.36$	$48.5^{a} \pm 0.40$	0.245
Heart fat (%)	$0.3^{a} \pm 0.02$	$0.3^{a} \pm 0.02$	$0.3^{a} \pm 0.02$	0.956
Kidney fat (%)	$2.8^{a} \pm 0.15$	$2.7^{a} \pm 0.15$	$2.6^{a} \pm 0.17$	0.799
Visceral fat (%)	$3.0^{a} \pm 0.12$	$3.0^{a} \pm 0.12$	$3.1^{a} \pm 0.14$	0.9001

^{a,b} Row means with different superscripts differ significantly ($P \leq 0.05$)

The following production and carcass yield parameters were influenced by gender: ADG, slaughter and carcass weight. Refer to Tables 3.30 – 3.35 and Figures 3.16 – 3.18 for the influence of gender on the production, wool and carcass yield parameters.

Table 3.30 Least square means (± s.e.) depicting the effect of gender on the production parameters of SAMM lambs during Experiment 2

Production Parameters	Gender		
	Ewe	Wether	P-Value
Starting weight (kg)	$42.3^{a} \pm 0.61$	$47.3^{b} \pm 0.64$	<0.0001
Slaughter weight (kg)	$52.7^{a} \pm 0.77$	$57.5^{b} \pm 0.80$	<0.0001
Total feed intake (kg)	$49.4^{a} \pm 0.85$	$51.2^{a} \pm 0.88$	0.151
Feed intake (kg per day)	$1.3^{a} \pm 0.02$	$1.4^{a} \pm 0.02$	0.165
FCR (kg feed/kg weight gain)	$4.9^{a} \pm 0.18$	$4.8^{a} \pm 0.19$	0.567
ADG (g)	$199.4^{a} \pm 38.64$	$231.1^{b} \pm 41.43$	<0.0001

^{a,b} Row means with different superscripts differ significantly ($P \leq 0.05$)

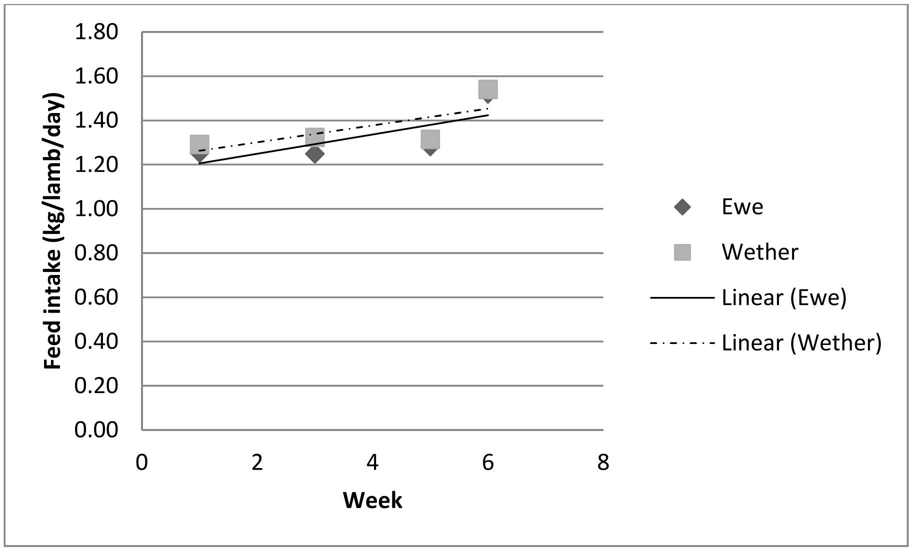

Figure 3.16 Linear regression of weekly feed intake (kg/lamb daily) as per gender in Experiment 2

A slow upward trend in the feed intake of lambs of both genders was observed with an increase in age.

Table 3.31 Linear regression equations of weekly feed intake (kg/lamb/day) of South African Mutton Merino lambs in Experiment 2

Gender	Linear regression equation	R^2
Ewe	y = 0.0436x + 1.1623	0.5494
Wether	y = 0.0382x + 1.2247	0.5354

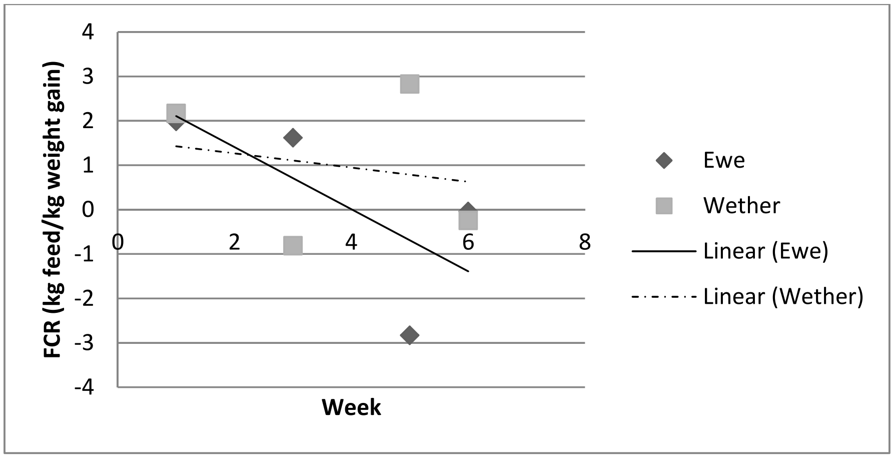

Figure 3.17 Linear regression of the weekly feed conversion ratio (kg feed/kg weight gain) as per gender in Experiment 2

A gradual decline in the feed conversion ratio of wethers was observed, while the decline in FCR with age in ewes was more rapid.

Table 3.32 Linear regression equations of the weekly feed conversion (kg feed/kg weight gain) ratio of SAMM lambs in Experiment 2

Gender	Linear regression equation	R^2
Ewe	y = -0.6993x + 2.8073	0.4989
Wether	y = -0.1602x + 1.5881	0.0397

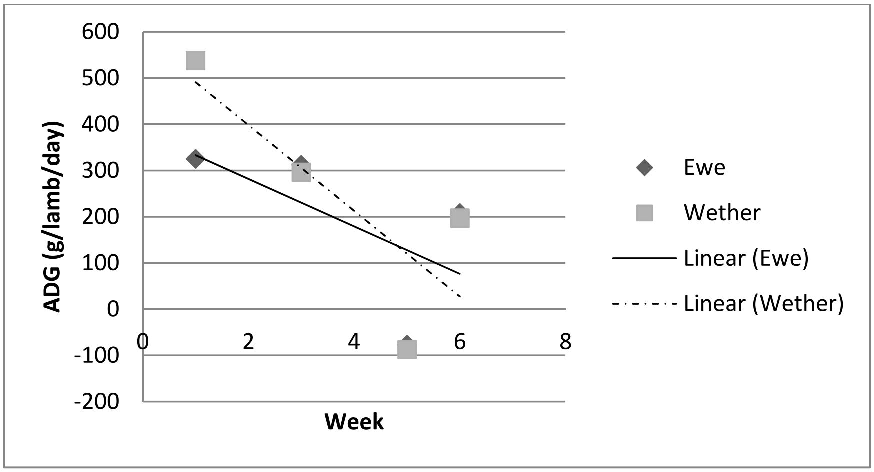

Figure 3.18 Linear regression of weekly weight gain (g/lamb daily) as per gender in Experiment 2

A rapid decline in the weight gain with an increase in age of both wethers and ewes was observed.

Table 3.33 Linear regression equations of weekly weight gain (g/lamb/day) of SAMM lambs in Experiment 2

Gender	Linear regression equation	R^2
Ewe	y = -51.254x + 384.20	0.3701
Wether	y = -92.678x + 583.54	0.6314

Wethers had a significantly higher average daily gain (231.12 ± 41.43 (g/lamb/day) than ewes (199.36 ± 38.64).

Table 3.34 Least square means (± s.e.) depicting the effect of gender on wool production parameters of SAMM lambs during Experiment 2

Wool Parameters	Gender		
	Ewe	Wether	P-Value
Fleece weight (kg)	$1.58^a \pm 0.04$	$1.65^a \pm 0.04$	0.216
Micro fibre diameter (µm)	$22.67^a \pm 0.20$	$22.74^a \pm 0.20$	0.822
Comfort factor (%)	$95.8^a \pm 0.59$	$96.1^a \pm 0.60$	0.686
Crimp length (mm)	$49.05^a \pm 0.78$	$47.92^a \pm 0.79$	0.313

^{a,b} Row means with different superscripts differ significantly ($P \leq 0.05$)

None of the wool parameters were influenced by gender.

Table 3.35 Least square means (± s.e.) depicting the effect of gender on carcass yield parameters of SAMM lambs during experiment 2

Carcass Yield Parameters	Gender		
	Ewe	Wether	P-Value
Carcass weight (kg)	$25.4^{a} \pm 0.43$	$28.0^{b} \pm 0.45$	<0.0001
Dressing percentage (%)	$48.3^{a} \pm 0.30$	$48.8^{a} \pm 0.31$	0.262
Heart fat (%)	$0.3^{a} \pm 0.01$	$0.7^{a} \pm 0.02$	0.588
Kidney fat (%)	$2.7^{a} \pm 0.13$	$2.7^{a} \pm 0.13$	0.644
Visceral fat (%)	$3.1^{a} \pm 0.10$	$2.9^{a} \pm 0.11$	0.115

[a,b] Row means with different superscripts differ significantly ($P \leq 0.05$)

Ewes had significantly lower slaughter (52.7 ± 0.77 kg) and carcass masses (25.4 ± 0.43 kg) than wether lambs (57.5 ± 0.80 and 28.0 ± 0.45 kg respectively). Whether lambs had a higher ADG, indicating that they put on weight faster than the ewes, resulting in the higher live mass at slaughter and carcass weight.

3.4 DISCUSSION

Krause & Oetzel (2006) found that the rumen pH was the highest in the mornings before the trial animals were fed and decreased between by 0.5 – 1.0 units within 6 hours of feeding. Overall none of the diets used in this study resulted in more than a unit decline in the rumen pH after feeding.

Williams *et al*. (1984) found that the cellulolytic activity in the rumen started to become depressed at a rumen pH below 6.2, while Lean *et al*. (2007) found that rumen cellulolysis was totally inhibited at a pH below 6.0. This could suggest that fibre digestibility was less than desirable for the diets used in this trial (especially of the medium and high energy level diets), which in turn could negatively affect the production of the lambs. The rumen pH of the lambs on the low energy diet was well above 6.2 for about 2 hours after feeding. It is particularly critical for low energy diets to have optimal levels of fibre digestion due to their high fibre content.

When the pH in the rumen is maintained above 5.5 it is indicative of equilibrium between the utilizers and producers of lactic acid becoming established, thereby preventing the accumulation of lactic acid in the rumen and avoiding a decline in pH (Lean *et al*., 2007). However, when the pH drops below 5.5 important microorganisms such as the cellulolytic and saccharolytic bacteria can no longer survive, while *Lactobacilli* (lactic acid producing bacteria) thrive (Lean *et al*., 2007). As the rumen pH declines to 5.0 and below increasing numbers of bacteria and protozoan populations die. The subsequent drop in rumen pH also causes chemical damage to the surface epithelium of the rumen mucosa and the rumen papillae are damaged, which can lead to acidosis and death if left untreated.

In order to prevent acidosis of the rumen as well as maximise growth performance, buffers are commonly included in feeds to try and stabilize the pH within a range suitable for optimal digestion (Lean *et al*., 2007; Walker, 2006). The saliva that is mixed with the feed during mastication also has a buffering effect in the rumen (Lean *et al*., 2007) due to its bicarbonate content. For a buffer to be effective in the rumen it must be water soluble and a weak acid (Lean *et al*., 2007). The buffer must minimise the decline in rumen pH without increasing the pH above the desired range (Lean *et al*., 2007). Buffers commonly used in the industry include sodium bicarbonate, potassium bicarbonate, magnesium carbonate and calcium carbonate (limestone), with sodium bicarbonate being the most popular buffer at present (Lean *et al*., 2007). Both sodium bicarbonate and limestone were included in the experimental diets used in this trial (Table 3.1). This is most likely why the overall pH of the fistulised sheep in this trial never dropped below 5.5, remaining high enough to prevent lactic acid from accumulating and thus rumen acidosis.

At the start of this experiment the inclusion of the β-AA in the diet was expected to result in an increase in the ADG, a decrease in the deposition of adipose tissue, an increase in skeletal muscle mass, an increase in the dressing percentage, an increase in muscle weight and a decrease in DM intake, as based on the results of a number of previously published studies (Beckett *et al*., 2009; Eckerman *et al*., 2011; Lopez-Carlos *et al*., 2010; Mersmann, 1998; Beermann, 2002). However this was not found, with none of the parameters being affected. It is speculated that this may have been due to the inclusion rate of the β-AA being too low, or alternatively the lambs used being too young to respond to its inclusion. Baker *et al*. (1984) found that the effects of β-AAs are more profound in more mature lambs.

For both groups of the β-AA treatment (included or absent) an increase in both feed intake and FCR was observed with an increase in the age of the lambs, while a decrease was noted in the ADG. Therefore the lambs consumed more feed but did not necessarily turn it into meat.

In both experiments the feed intake and FCR increased with an increase in age except for the lambs on the low dietary energy level of the second experiment. These lambs showed a decrease in FCR with an increase in age. The ADG of the lambs in both experiments decreased as the lambs age increased as expected. Feed intake has in the past been found to decline when the diet contains less than 10% crude protein (CP) and increase with the inclusion of fibre up to 18.8%.

All three of the diets used contained more than 10% CP (13.34%, 13.43 and 14.09% respectively) and less than 18.8% fibre (13.80%, 10.30% and 7.30% respectively). The higher feed intake of the lambs fed the LE diet could be due to the lower energy density of the diet. This is in accordance with current literature. De Sousa *et al*. (2012) found that the feed intake of lambs that received a high energy level diet was lower than that of lambs that received a low energy level diet. It therefore appears evident that an increase in the energy density of a diet leads to a decrease in feed intake as long as intake is not otherwise constricted by interfering factors (Hossain *et al*., 2003; Sayed, 2011).

The higher slaughter and carcass weight of the lambs on the low dietary energy level is as a result of the higher feed intake and higher ADG. Beauchemin *et al*. (1995) established that an increase in dietary energy level results in an increase in growth rate.

An increase in the metabolisable energy content of the diet will decrease the feed intake of lambs as long as voluntary intake is not restricted by other factors such rumen fill or gastrointestinal (GI) health. This decrease in feed intake will lower the FCR and increase production efficiency. Although the energy density of diets is seen as the first limiting factor of production, the voluntary feed intake of lambs is influenced by various factors other than the energy density of diets. Factors such as rumen fill, GI health, palatability, physical form and composition of the diet also plays a role in the voluntary feed intake of lambs (Paladines *et al*., 1963; Valderrabano *et al*. 2002).

Murphy *et al.* (1994) and Priolo *et al.* (2002) found that both the meat and carcass quality of lambs with regard to fatness degree and carcass conformation is affected by the feeding systems. Moron-Fuenmayor & Clavero (1999) reported higher dressing percentages in lambs fed concentrates (higher energy density diets); this was consistent with a study by Cividini *et al.* (2007). Cividini *et al.* (2007) compared pasture lambs to concentrate fed lambs and found that the lambs on pasture had lower internal and carcass fat levels relative to the concentrate-fed lambs.

The same results for gender were observed in both experiments for feed intake and ADG which respectively increased and decreased with an increase in the age of the lambs. The FCR however for the rams and ewes in the first experiment increased with an increase in age while it decreased for the ewes and wethers in the second experiment.

Ewes had a significantly higher percentage of kidney fat than their ram counterparts. This supports the current view that ewes start accumulating fat at a younger age than rams. Butterfield (1988) found that ewes fatten up earlier while rams have a slower rate of maturation. Fat is a late maturing tissue, and since ewes mature at a faster rate than rams, it is natural that the ewes will deposit fat earlier than rams (Thu, 2006). This is in accordance with the results of Kirton *et al.* (1995) who found that ewe lambs deposited more total carcass fat and had larger individual fat depots than ram lambs. The physiological development of the rams and ewes also influences the carcass composition; ewes tend to be better developed in the hindquarters while rams are better developed in the fore-quarters or head and neck area (Johnson *et* al., 2005; Wolf *et al*., 2001).

The higher average daily gain of rams, compared to their ewes and wethers, make them more favourable for meat production as they can be slaughtered at a younger age than their ewe and wether counterparts (Notter *et* al., 1991). The higher slaughter and carcass weight of rams and wethers compared to the ewes in both trials are due to a better utilization of their feed and a higher ADG when compared to ewes; it can also be attributed to the larger mature body size of the ram (Kirton *et al*., 1995).

Although no significant differences were found in this study between the fat depots of the ewes and wethers, Notter *et al*. (1991) reported that wethers grow slower than rams but faster than ewes, and according to Butterfield (1988) ewes fatten up earlier than rams. Therefore when comparing lambs of different sexes at relatively the same age and live weight and fed the same diets, the ewes will normally fatten up first, followed by the wethers and then the ram lambs.

3.5 CONCLUSION

An overall gradual decline in the rumen pH was found for all the experimental diets used in this trial, although spikes were found for the LE and ME diets. It was also found that only the low energy diet's pH was ever above 6.2, the point after which cellulolytic activity becomes depressed and digestibility could be impaired. Although fibre digestion was most likely impaired on the ME and HE diets, the rumen pH environment was generally still positive for digestive bacteria and preventative of rumen acidosis.

The higher feed intake of the lambs in the first experiment resulted in a more expensive diet as the higher intake of the lambs used in experiment 1 resulted in more feed being required. It can be concluded that with an increase in age the lambs' growth and feed utilization efficiency decreased.

It was further concluded that neither the inclusion nor the absence of the β-AA in the diet had any effect on any of the parameters. This is in contrast to the expectation that the lambs receiving the β-AA would perform better. The feeding of a β-AA to livestock typically increases the ADG and improves feed efficiency (Beckett *et al*., 2009; Casey *et al.* 1997; Eckerman *et al*., 2011; Elam *et al*., 2009; Lopez-Carlos *et al*., 2010; Mersmann, 2002; Montgomery *et al*., 2009; Parr *et al*., 2011; Rathmann *et al*., 2009), decreases adipose tissue and increases skeletal muscle (Byrem *et al*., 1998; Holland, 2010; Lopez-Carlos *et al*., 2010; Mersmann, 1998, 2002; Rathmann *et al*., 2009). For further research it would be recommended to include the β-AA in the diet at higher inclusion levels.

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CHAPTER 4

THE EFFECT OF VARYING DIETARY ENERGY LEVELS AND THE INCLUSION OF A β-AGONIST IN THE DIET ON THE RELATIONSHIP BETWEEN SLAUGHTER WEIGHT, COMMERCIAL CUT YIELD AND BONE:FAT:MUSCLE RATIO OF SOUTH AFRICAN MUTTON MERINO FEEDLOT LAMBS

ABSTRACT

The study was conducted at Elsenburg Experimental Farm in the Western Cape of South Africa, using 108 South African Mutton Merino lambs. The lambs were obtained from Langgewens Experimental Farm, Western Cape, South Africa and weaned at *ca.* 120 days of age. One aim of this trial was to determine whether (and how) various energy level diets (diet 1 – 11.3 MJ ME/kg Feed, diet 2 – 12.0 MJ ME/kg feed and diet 3 – 12.7 MJ ME/kg feed) either containing (8.6 g/ton) or not containing a β-adrenergic agonist (β-AA) , affected the bone:muscle:fat ratio. The second aim of the trial was to predict the commercial cut yield and carcass parameters from the slaughter weight using linear regressions. The experiment was a 3 x 2 x 2 factorial design with dietary energy level (3), the provision of a β-AA (2) and gender (2) as main factors affecting the carcass parameters and tissue ratios. The main effects dietary energy level and gender affected the leg yield and fat percentage in the bone:muscle:fat ratio, respectively. The lambs on the LE (27.8 ± 0.23) had the highest leg yield compared to the lambs on the other dietary treatments, while the ewes (19.8 ± 0.78 vs. 17.6 ± 0.71) had a higher fat dress out percentage of the leg compared to the ram lambs. Positive correlations between slaughter weight and the following parameters were observed: carcass weight, leg yield, shoulder yield, neck yield, flank yield and cranial fat thickness.

4.1 INTRODUCTION

Carcass conformation is determined by the thickness of the muscle and subcutaneous fat in relation to the skeleton size (Costa *et al.*, 2010); also known as the relationship between bone:fat:muscle. These tissues have different maturation rates; with bone tissue typically maturing first, followed by the lean and fat tissue, respectively (Rouse *et al.*, 1970). The feed intake level, the age at which the lamb reaches maturity and the slaughter weight are the main factors that influence the bone:muscle:fat ratio of the carcass (Johnson *et al*., 2005; Kemp *et al*., 1976; Murphy *et al*., 1994).

It is beneficial for the lamb producer to produce meat with a high muscle to fat ratio as this will satisfy the health conscious consumer who prefers a leaner and lighter carcass. These consumers believe that meat from lighter carcasses is of better quality due to its less prominent flavour and greater tenderness in comparison to meat from heavier carcasses (Martinez-Cerezo *et al*., 2005).

The inclusion of a β-adrenergic agonist (β-AA) in the feed has been found to alter the muscle:fat relationship of the carcass (in beef), typically decreasing adipose tissue and increasing skeletal muscle mass(Lopez-Carlos *et al*., 2010; Mersmann, 1998 & Rathmann *et al*., 2009). However, very little research has been conducted evaluating the use of β-AA in sheep feedlot diets and quantifying the effect thereof on lean meat yield. This investigation evaluated the effect of the addition of β-AA in the diets of feedlot lambs containing different levels of energy. The aim of this trial was to determine the effect of the addition of a β-AA, different dietary energy levels and gender on the dress out percentage of bone:muscle:fat and the relationship between slaughter weight and commercial cut yields.

4.2 MATERIAL AND METHODS

4.2.1 Animals and sampling

South African Mutton Merino (108) ram and ewe lambs were obtained from Langgewens Experimental Farm in the Western Cape of South Africa. The lambs were weaned at *ca.* 120 days of age. The lambs were subsequently transported from Langgewens to the experimental site, Elsenburg Experimental Farm, also situated in the Western Cape of South Africa. On arrival at the experimental site the lambs were randomly allocated to one of six groups (18 lambs/group of equal number of rams and ewes/group; Figure 4.1) and vaccinated against pulpy kidney/enterotoxaemia (withdrawal period of 21 days; OBP, 1947) under normal feedlot conditions. The lambs were housed in pens (the size of which were within the norms described by animal welfare guidelines; 117 x 177 cm).

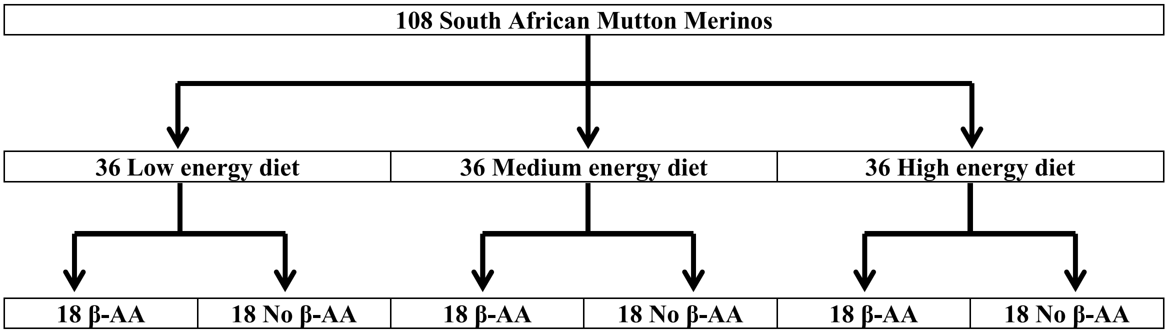

Figure 4.1 Schematic representation of the trial

The treatments consisted of three different energy level diets (11.3 MJ ME/kg feed; 12.0 MJ ME/kg feed and 12.7 MJ ME/kg feed; Table 4.1). These diets were further divided according to whether or not a β-AA was included at 8.6 g/ton. The β-AA was withdrawn from the diet three days prior to the slaughter of the lambs (Shelver & Smith, 2006).

Table 4.1 The formulation of the diets used in this trial

Ingredients	Diets % (As Is)		
	LE	**ME**	**HE**
Maize	44.30	54.90	65.50
Lucerne	40.00	25.90	11.80
Cottonseed Oilcake	8.00	11.45	14.89
Molasses Powder	2.500	2.50	2.50
Salt (NaCl)	1.00	1.00	1.00
Bicarbonate of Soda	1.00	1.00	1.00
Ammonium chloride	1.00	1.00	1.00
Limestone	0.90	1.10	1.30
Urea	0.50	0.50	0.50
Mono Calcium Phosphate	0.34	0.18	0.02
Vitamin & Mineral "Premix"	0.25	0.25	0.25
Sulphur	0.20	0.20	0.20
Growth promoters & Ionophores (Stafax, Tauratec & Thylan)	0.02	0.02	0.02
Total	**100**	**100**	**100**

The lambs were fed a restricted diet and were provided with fresh clean water daily. Feed refusals were weighed back once a week and lamb live mass was also determined on a weekly basis. The lambs remained in the feedlot for a period of approximately six weeks.

The lambs were sheared a week before slaughter and were slaughtered at a weight of ± 54 kg, higher than the average commercial weight (± 40 kg) in order to determine whether the use of the β-AA affected the bone:muscle:fat ratio and the proportion of commercial cuts in heavier feedlot lambs.

The lambs were weighed twenty-four hours prior to slaughter, with this mass being used as the final live weight of the lambs. Once the target weight had been reached the lambs were transported from the experimental site to a registered sheep abattoir (Roelcor, Malmesbury, Western Cape, South Africa), where they were slaughtered using standard South African techniques (Cloete *et al*., 2004). No electrical stimulation was applied.

4.2.2 Instrumental analyses

The carcass pH was measured 45 minutes *post mortem*, just prior to the carcasses being placed in the cooling unit at 4°C for 48 hours. The pH was measured in the *Longissimus dorsi* muscle between the 2nd and 3rd last thoracic vertebrae. After 48 hours in the cooling unit the carcasses were weighed to determine the dressing percentage and the pH for each carcass was measured at the same position as on the day of slaughter.

Once the pH reading had been taken the carcasses were cut into the normal commercial cuts. Each cut was weighed as an entity to determine the yield thereof. After 48 h in cold storage (4°C) the carcasses were weighed and partitioned into South African retail cuts (Figure 4.2), which were weighed separately (Cloete *et al*., 2004). The right legs were packed, cooled and transported to the laboratory for further analyses. Each leg was then weighed intact, where after it was dissected into its bone, muscle and fat components. These components were weighed individually to determine the bone:muscle:fat ratio of the cut, which was expressed as a percentage of the leg weight.

The *Longissimus dorsi* (LD) was removed between the 9th and 12th rib on which the fat thickness was measured. The thickness was measured on both the cranial (the part of the muscle removed closest to the head of the carcass) and caudal (the part of the muscle removed closest to the tail of the carcass) side of the muscle.

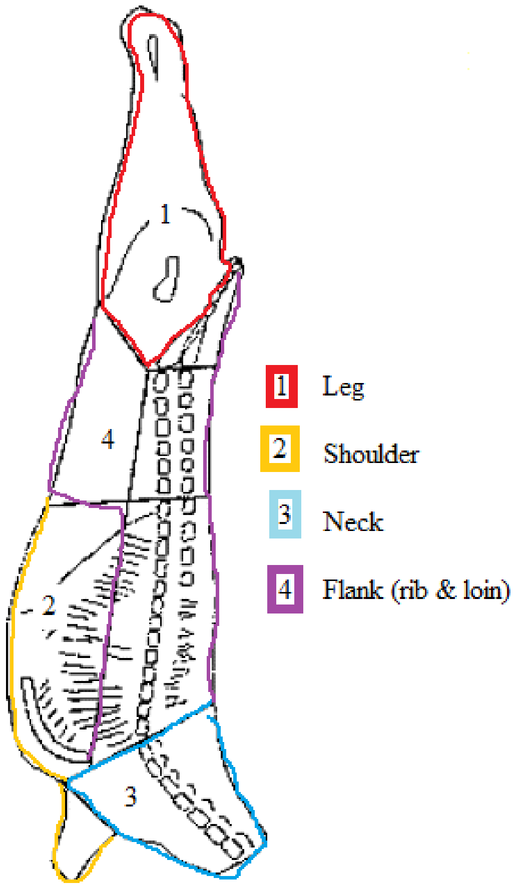

Figure 4.2 Representation of the various trading cuts

4.2.3 Statistical analyses

The experiment consisted of a completely randomised design with six treatments. The treatment design was a 3 (dietary energy level) x 2 (β-AA absent or included in the diet) x 2 (ram/ewe) factorial design.

A factorial analysis of variance was performed on the data using SAS for Windows Version 9.1.3 Proc GLM (SAS, 2000), while normality was tested using the Shapiro-Wilk test (Shapiro & Wilk, 1965). Outliers which caused deviations from normality were removed prior to the final analysis. Student's t-Least Significant Differences (LSD) were calculated at the 5% significance level to compare treatment means.

A linear regression analysis was also performed on the data set using SAS for Windows Version 9.1.3 Proc. REG. This regression was subsequently used to predict the commercial cut yields from the final live slaughter weight.

4.3 RESULTS

Linear regressions were performed between the slaughter weight of the lambs and the following parameters: carcass weight (Figure 4.3 and Table 4.2), dressing percentage (Figure 4.4 and Table 4.3), leg (Figure 4.5 and Table 4.4), shoulder (Figure 4.6 and Table 4.5), flank (Figure 4.8 and Table 4.6), neck (Figure 4.7 and Table 4.7), fat thickness caudal (Figure 4.9 and Table 4.8) and fat thickness cranial (Figure 4.10 and Table 4.9).

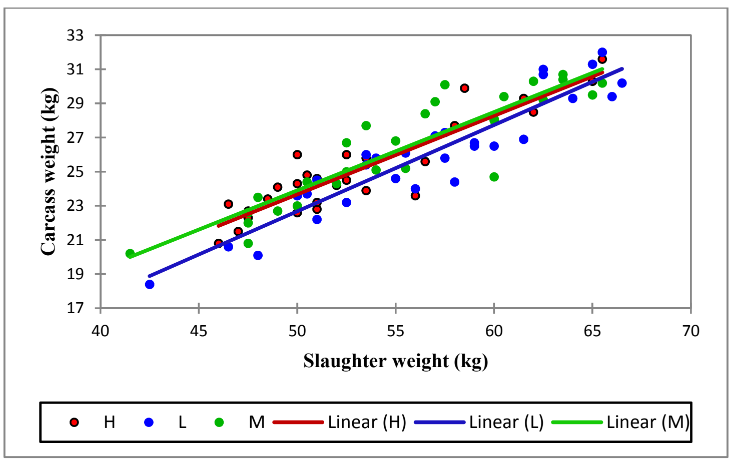

Figure 4.3 Linear regressions of carcass weight on slaughter weight for SAMM lambs fed diets with three different energy levels (low, medium and high)

Table 4.2 Equations of the linear regression curves of carcass weight on slaughter weight of SAMM lambs fed three different dietary energy levels

Diet	Equation	R^2
LE	y = 0.5057x – 2.6069	0.8327
ME	y = 0.4589x + 0.9581	0.8226
HE	y = 0.4611x + 0.6128	0.8327

Linear regression models for the lambs on the LE and HE diets had the same degree of accuracy of prediction (0.8327), with the accuracy of prediction of the ME model being slightly lower (0.8226). A positive correlation between the slaughter weight and the carcass weight can be seen for all three dietary energy levels.

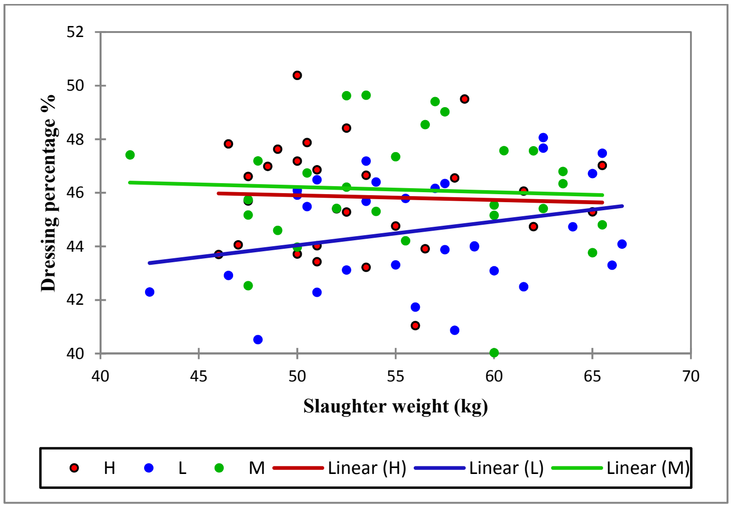

Figure 4.4 Linear regressions of dressing percentage on slaughter weight of SAMM lambs fed different dietary energy level diets

The individual models are not very accurate (as seen by the low R^2 values), thus indicating that very little of the variation present in the data is explained by the models (Table 4.10). However, a weak positive correlation between slaughter weight and dressing percentage is observed for the low dietary energy level. In contrast, a weak negative correlation is observed between slaughter weight and carcass weight for both the high and medium energy level diets.

Table 4.3 Equations of linear regressions of dressing percentage on slaughter weight of SAMM feedlot lambs fed three different dietary energy level diets

Diet	Equation	R^2
LE	y = 0.0886x + 39.613	0.0694
ME	y = 0.0194x + 47.184	0.0031
HE	y = -0.0171x + 46.762	0.0020

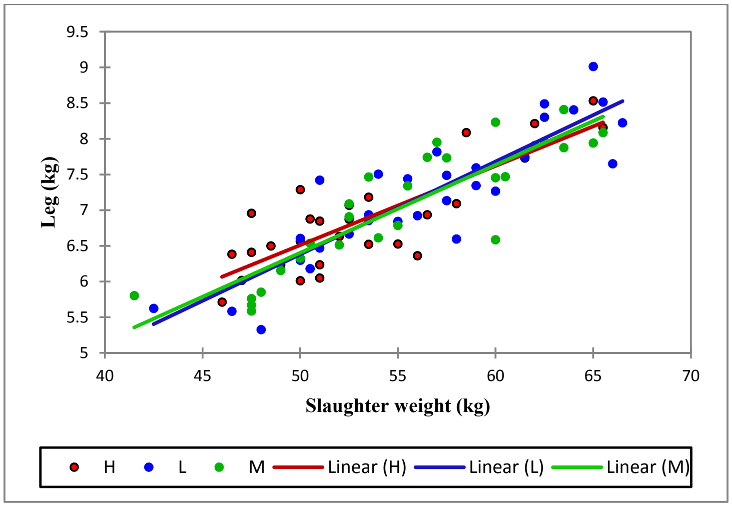

Figure 4.5 Linear regressions of hind leg yield on slaughter weight of SAMM feedlot lambs fed different dietary energy levels

A great deal of the variation in the data is explained by the individual models (Table 4.11), with a relatively high level of accuracy being indicated by the R^2 values. Positive correlations between slaughter weight and leg yield are observed and an increase in slaughter weight will thus result in an increase in leg yield.

Table 4.4 Equations for the linear regressions of hind leg yield on slaughter weight of SAMM feedlot lambs fed three different dietary energy levels

Diet	Equation	R^2
LE	y = 0.1302x – 0.1279	0.7851
ME	y = 0.1230x + 0.2565	0.7864
HE	y = 0.1109x + 0.9648	0.6907

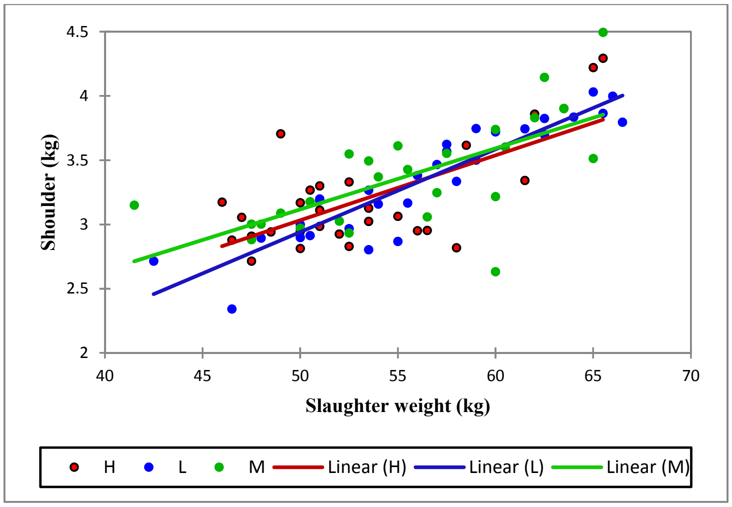

Figure 4.6 Linear regressions of shoulder yield on slaughter weight of SAMM feedlot lambs fed three different dietary energy level diets

The model for the shoulder yield of the lambs fed the LE diet has a relatively high R^2 value (0.8441), indicating that a large proportion of the variation present in the data is explained by the model. The models for ME and HE have low R^2 values (0.4838 and 0.4602 respectively; Table 4.12), and explain little of the variation in the data. Although poor accuracy is observed, all the models showed a positive correlation between slaughter weight and shoulder yield as per dietary energy level.

Table 4.5 Equations of linear regressions of shoulder yield on slaughter weight of SAMM feedlot lambs fed three different dietary energy level diets

Diet	Equation	R^2
LE	y = 0.0644x – 0.2786	0.8441
ME	y = 0.0476x + 0.7388	0.4838
HE	y = 0.0505x + 0.5048	0.4602

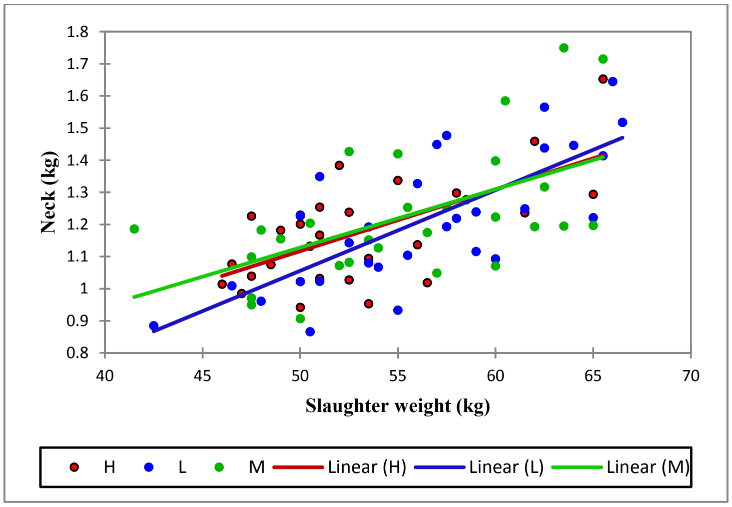

Figure 4.7 Linear regressions of neck yield on slaughter weight of SAMM feedlot lambs fed three different dietary energy levels

The model for the LE diet is more accurate (0.5544) than the models for the ME and HE diets (0.3101 and 0.4149 respectively; Table 4.13). Although very little variation is explained by the models, a positive linear correlation is still observed between slaughter weight and neck yield as per energy treatment. With an increase in the lambs' slaughter weight an increase in neck yield is observed.

Table 4.6 Equations of linear regressions of neck yield on slaughter weight of SAMM feedlot lambs fed three different energy level diets (low, medium and high)

Diet	Equation	R^2
LE	y = 0.0251x – 0.1998	0.5544
ME	y = 0.0182x + 0.2203	0.3101
HE	y = 0.0193x + 0.1543	0.4149

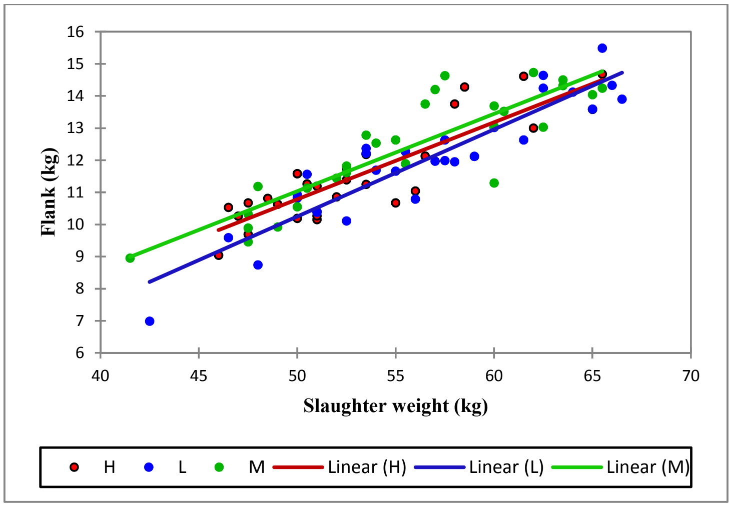

Figure 4.8 Linear regressions of flank yield on slaughter weight of SAMM feedlot lambs fed three different dietary energy levels

The model for the regression of the flank yield on the slaughter weight for the lambs on the low energy diet was more accurate (0.848) than that for the lambs on the ME (0.7756) and HE (0.7663) diets (Table 4.14). However all three models explain a large portion of the variation present in the data. Positive correlations are observed for all three models or dietary energy levels, indicating that with an increase in slaughter weight an increase in flank yield is observed.

Table 4.7 Equations of the linear regressions of flank yield on slaughter weight of SAMM feedlot lambs fed three different dietary energy levels

Diet	**Equation**	**R^2**
LE	y = 0.2713x – 3.3157	0.8480
ME	y = 0.2406x – 0.9936	0.7756
HE	y = 0.2397x – 1.1995	0.7663

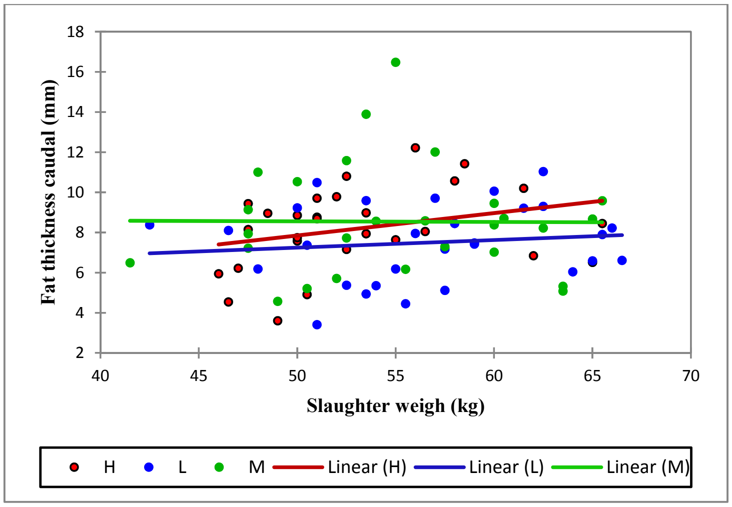

Figure 4.9 Linear regressions of caudal fat thickness on slaughter weight for the individual dietary energy levels fed to SAMM feedlot lambs

All three models have a very low level of accuracy (Table 4.15; R^2-values), indicating that almost none of the variation is explained by the model. The lambs on the high energy diet show a very weak positive correlation between the slaughter weight and the caudal fat thickness, while the lambs on the LE and ME diets show no correlation between the slaughter weight and the caudal fat thickness.

Table 4.8 Equations of the linear regressions of caudal fat thickness on slaughter weight of SAMM feedlot lambs fed three different dietary energy levels

Diet	**Equation**	**R^2**
LE	y = 0.0376x + 5.3629	0.01470
ME	y = -0.003x + 8.7057	0.00005
HE	y = 0.1116x + 2.2746	0.08890

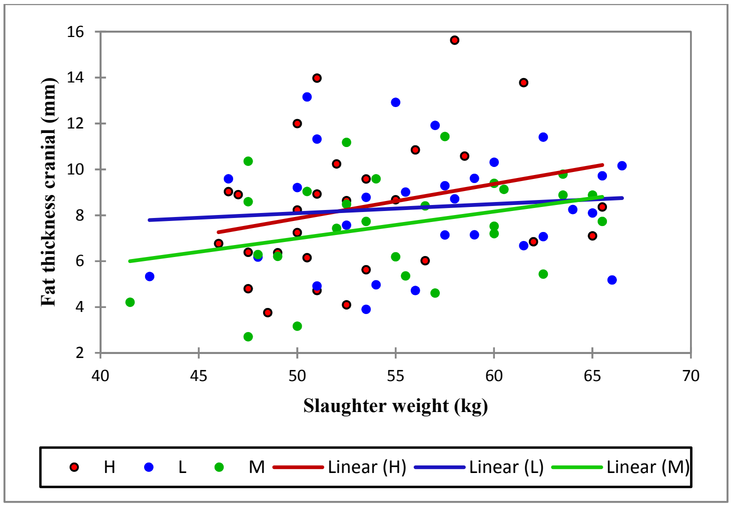

Figure 4.10 Linear regressions of cranial fat thickness on slaughter weight of SAMM feedlot lambs fed three different dietary energy levels

All three models have a very low level of accuracy (Table 4.16; R^2-values), indicating that almost none of the variation is explained by the model. The lambs on the all three dietary energy levels show a very weak positive correlation between the slaughter weight and the cranial fat thickness.

Table 4.9 Equations of the linear regressions of cranial fat thickness on slaughter weight of SAMM feedlot lambs fed three different dietary energy levels

Diet	Equation	R^2
LE	y = 0.0401x + 6.0855	0.0098
ME	y = 0.1168x + 1.1557	0.1032
HE	y = 0.1505x + 0.3375	0.0750

Apart from for the commercial neck cut, none of the data showed any interactions between the main effects, thus allowing the main effects to be interpreted separately (Tables 4.10 – 4.15). No significant differences were found on the dress out percentages of bone:muscle:fat as per treatment dietary energy.

Table 4.10 Least square means (± s.e.) depicting the effect of dietary energy on the various commercial cuts of the carcass of SAMM feedlot lambs

Parameter	LE	ME	HE	P-Value
Leg (%)	$27.8^{a} \pm 0.23$	$26.8^{b} \pm 0.23$	$27.4^{a,b} \pm 0.23$	0.013
Shoulder (%)	$12.9^{a} \pm 0.21$	$12.9^{a} \pm 0.21$	$12.8^{a} \pm 0.21$	0.931
Neck# (%)	4.6 ± 0.10	4.7 ± 0.10	4.7 ± 0.10	0.770
Flank (%)	$46.3^{a} \pm 0.37$	$46.6^{a} \pm 0.38$	$46.0^{a} \pm 0.38$	0.583
Fat thickness caudal (mm)	$7.55^{a} \pm 0.43$	$8.61^{a} \pm 0.44$	$8.15^{a} \pm 0.43$	0.395
Fat thickness cranial (mm)	$8.53^{a} \pm 0.50$	$7.57^{a} \pm 0.51$	$8.28^{a} \pm 0.50$	0.243

a,b Row means with different superscripts differ significantly ($P \leq 0.05$)

#Due to interaction main effects cannot be interpreted

Dietary energy level only affected the commercial yield of the leg cut. The leg yield of the lambs that received the low dietary energy level (27.8 %) were significantly heavier than the leg yield of those that received the medium dietary energy level (26.8 ± 0.23). However, the leg yield of the lambs on the HE diet was intermediate and did not differ (P>0.05) from that of the lambs fed either the ME or LE diets. There were no significant differences between dietary energy for fat thickness, which was consistent with findings of Jones *et al*. (1983).

Table 4.11 Least square means (± s.e.) depicting the effect of dietary energy level on the bone:muscle:fat ratio of SAMM feedlot lambs

Parameter	LE	ME	HE	P-Value
Bone (%)	$17.2^{a} \pm 0.42$	$16.8^{a} \pm 0.43$	$17.8^{a} \pm 0.43$	0.292
Muscle (%)	$63.5^{a} \pm 0.84$	$65.1^{a} \pm 0.87$	$63.6^{a} \pm 0.85$	0.361
Fat (%)	$19.3^{a} \pm 0.89$	$18.1^{a} \pm 0.92$	$18.7^{a} \pm 0.90$	0.678

a,b Row means with different superscripts differ significantly ($P \leq 0.05$)

The use of the β-AA had no influence on any of the yields of the commercial cuts nor on the ratio of bone:muscle:fat (Tables 4.12 and 4.13, respectively).

Table 4.12 Least square means (± s.e.) depicting the effect of the inclusion of a β-AA on the various commercial cuts of the carcass of SAMM feedlot lambs

Parameter	β-AA		
	Absent	Included	P-Value
Leg (%)	$27.4^a \pm 0.45$	$27.3^a \pm 0.45$	0.792
Shoulder (%)	$12.9^a \pm 0.17$	$12.8^a \pm 0.17$	0.523
Neck[#] (%)	4.6 ± 0.08	4.8 ± 0.08	0.184
Flank (%)	$46.2^a \pm 0.31$	$46.4^a \pm 0.31$	0.533
Fat thickness caudal (mm)	$8.46^a \pm 0.35$	$7.75^a \pm 0.35$	0.417
Fat thickness cranial (mm)	$8.36^a \pm 0.41$	$7.89^a \pm 0.41$	0.158

[a,b] Row means with different superscripts differ significantly ($P \leq 0.05$)

[#]Due to interaction main effects cannot be interpreted

The dietary energy level had no effect on the relationship between bone, muscle and fat. This was contrary to expectations, as it was expected that lambs fed the higher energy diet would have a higher proportion of fat in the carcass.

Table 4.13 Least square means (± s.e.) depicting the effect of the inclusion of a β-AA on the relationship between bone:muscle:fat of SAMM feedlot lambs

Parameter	β-AA		
	Absent	Included	P-Value
Bone (%)	$17.4^a \pm 0.34$	$17.2^a \pm 0.35$	0.704
Muscle (%)	$62.3^a \pm 0.69$	$63.9^a \pm 0.70$	0.715
Fat (%)	$18.4^a \pm 0.73$	$19.0^a \pm 0.74$	0.600

[a,b] Row means with different superscripts differ significantly ($P \leq 0.05$)

Table 4.14 Least square means (± s.e.) depicting the effect of gender on the various commercial cuts of the carcass of SAMM feedlot lambs

Parameter	Ewe	Ram	P-Value
Leg (%)	$27.3^{a} \pm 0.19$	$27.4^{a} \pm 0.18$	0.592
Shoulder (%)	$12.6^{a} \pm 0.18$	$13.1^{b} \pm 0.17$	0.038
Neck[#] (%)	4.6 ± 0.08	4.8 ± 0.08	0.063
Flank (%)	$46.6^{a} \pm 0.32$	$46.0^{a} \pm 0.30$	0.132
Fat thickness caudal (mm)	$8.47^{a} \pm 0.37$	$7.73^{a} \pm 0.34$	0.139
Fat thickness cranial (mm)	$8.58^{a} \pm 0.43$	$7.73^{a} \pm 0.34$	0.161

[a,b] Row means with different superscripts differ significantly ($P \leq 0.05$)

[#]Due to interaction main effects cannot be interpreted

No significant differences (P>0.05) were found between the genders for the different commercial cut yields, although it was expected that the ewe lambs would have a higher yield in the leg cuts and the rams a higher yield in the neck/shoulder cuts.

Table 4.15 Least square means (± s.e.) depicting the effect of gender on the bone:muscle:fat ratio of SAMM feedlot lambs

Parameter	Ewe	Ram	P-Value
Bone (%)	$16.9^{a} \pm 0.37$	$17.6^{a} \pm 0.34$	0.135
Muscle (%)	$63.3^{a} \pm 0.74$	$64.8^{a} \pm 0.67$	0.160
Fat (%)	$19.8^{a} \pm 0.78$	$17.6^{b} \pm 0.71$	0.044

[a,b] Row means with different superscripts differ significantly ($P \leq 0.05$)

The proportion of fat relative to muscle and bone of the ewes (19.8) was significantly (P<0.05) higher than that of the ram (17.6) lambs (Table 4.15).

The presence of interactions between the main effects for the neck cut (Table 4.16) prevented the individual interpretation of the main effects for this cut.

Table 4.16 Least square means (± s.e.) depicting the interaction between the main factors for the neck cut of the SAMM feedlot lambs

Parameter	Gender	β-AA	Diet	LSM ± SE
Neck (%)	F	N	HE	4.6 ± 0.19
	F	N	LE	4.3 ± 0.23
	F	N	ME	4.8 ± 0.23
	F	Y	HE	4.7 ± 0.18
	F	Y	LE	4.5 ± 0.21
	F	Y	ME	4.6 ± 0.18
	M	N	HE	4.9 ± 0.19
	M	N	LE	4.8 ± 0.16
	M	N	ME	**4.3^{a}** ± 0.17
	M	Y	HE	4.6 ± 0.23
	M	Y	LE	4.9 ± 0.17
	M	Y	ME	**5.2^{b}** ± 0.21

^{a,b} Column means with different superscripts differ significantly (P ≤ 0.05)

4.4 DISCUSSIONS

The positive linear correlation for the low dietary energy level between slaughter weight and dressing percentage and the negative correlation for both the high and medium energy level between slaughter weight and dressing percentage could be due to the fact that the dressing percentage of lambs is affected by both the weight of the skin and wool as well as the stomach contents (Kirton *et al*., 1995), which should however not affect the lambs in this experiment since all of the lambs were shorn at the same time. Sayed (2009) found that the dressing percentage of lambs increased when feeding a high dietary energy diet, with an increase in fatness. However in this study there were no significant different found between the fat dress out percentage or fat thickness for the lambs on either the LE, ME or HE diet, with a weak linear decrease in dressing percentage with an increase in slaughter weight.

The commercial yield of the leg cut was affected by dietary energy. An increase in carcass weight leads to an increase in fat in relation to the total carcass mass, and thus to a decrease in retail cut yields (Carpenter *et al*., 1964). However no significant differences were found between the fat dress out percentage between the lambs on all three dietary energy diets, therefore the higher leg yield of the lambs on the LE diet cannot be contributed to a higher fat dress out percentage, although it would have been expected for the lambs on the HE to have a higher fat dress out (Sayed 2009). The late maturing nature of fat tissue can also not be contributed to this fact due to the fact that the lambs were slaughtered at the same age. Kemp *et al*. (1970) found that with an increase in slaughter weight the yield of the leg, shank, and bone decreased, while the breast, flank and kidney yields increased. The findings in this trial were both in accordance and contradictory to Kemp *et al*. (1970). The findings in this trial were that with an increase in slaughter weight all of the following parameters increased linear: carcass weight, leg-, shoulder-, neck- and flank yield.

Although no significant differences were found in the fat dress out percentage or in the fat thickness between the three dietary energy levels, it was expected that the lambs on the HE diet would have both an increased fat dress out percentage and fat thickness. Sayed (2009) found that lambs fed diets with high energy content had an increased live weight at slaughter, organ weight, body fat and dressing percentage. It is however greatly accepted that increasing dietary energy levels results in increasing fat deposition (Ebrahimi *et al*., 2007), which was however not the case in this study.

Contrary to expectations, the inclusion of the β-AA in the diet did not result in any change in the bone:muscle:fat ratio relative to that of the lambs receiving the diet without the β-AA. This is despite the fact that β-AA's have previously been found to increase the proportion of lean muscle and decrease the proportion of fat in the carcass (Lopez-Carlos *et al*., 2010; Mersmann, 2002). Neither the absence nor the inclusion of the β-AA in the diet had a significant effect ($P>0.05$) on the commercial cut yields, contrary to the expectation that the presence of the β-AA in the diet would increase the cutability (Hilton *et al*., 2009).

The proportion of fat relative to muscle and bone of the ewes was significantly ($P<0.05$) higher than that of the ram lambs. This is consistent with findings in current literature when lambs are slaughtered at the same live weight; for example, Kirton *et al*. (1995) established that ewe lambs deposit more total carcass fat than ram lambs. Jones *et al*. (1983) established that although ewes had a faster fat accumulation rate, both genders generally follows the same pattern of fat accumulation. Although it was expected that the rams would have heavier neck cuts due to heavier forequarters in male sheep (Jeremiah *et al*., 1997), it was however not the case in this study. It was however noted that in the interaction between gender, β-AA and diet the ram lambs that did receive the β-AA on the ME diet had a significantly heavier neck cut than the ram lambs that did not receive the β-AA on the ME diet (Table 4.16).

No differences (P>0.05) were found between the genders for the different commercial cut yields, although it was expected that the ewe lambs would have a higher yield in the leg cuts and the rams a higher yield in the neck/shoulder cuts. This expectation was based on an established body of literature in which it has been found that ewes are better developed in the hindquarters while rams are more developed in the forequarters (Fahmy *et al*., 1999; Johnson *et al*., 2005; Wolf *et al*., 2001). A possible explanation for this lack of differences could be that the lambs were still relatively young when slaughtered and had thus not yet reached sexual maturity when these differences are normally more prominent. Ageing of the lamb leads to the maturation of the tissues. The order in which the tissue mature is bone, muscle and fat (Rouse *et al*., 1970). The effect of gender was not as pronounced in this experiment as expected due to the fact that the lambs were slaughtered at a young age before sexual maturity was reached for gender effects to fully shown a significant effect.

4.5 CONCLUSION

Of the three main effects, only dietary energy and gender affected the various carcass parameters. The lambs on the low dietary energy level had the highest leg yield, while ewes had a higher fat percentage than rams which changed their the bone:muscle:fat ratio.

Contrary to expectations that the β-AA would increase the lean yield (Lopez-Carlos *et al*., 2010; Mersmann, 2002) the β-AA had no effect on either of the commercial cut yields or the muscle dress out percentage. Further research into the use of higher inclusion levels of the β-AA is recommended in order to determine the effect of the β-AA on the commercial cut yields as well as the dress out percentages of bone:muscle:fat. It is recommended to include the β-AA at higher inclusion levels in the diet to observe better results, for instance the alteration of the bone:muscle:fat ratio – more lean meat.

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CHAPTER 5

THE EFFECT OF DIETARY ENERGY AND THE PROVISION OF A β-AGONIST ON THE MEAT QUALITY OF SOUTH AFRICAN MUTTON MERINO FEEDLOT LAMBS*

*Partly published as: The effect of dietary energy and the inclusion of a β-adrenergic agonist in the diet on the meat quality of feedlot lambs. T.S. Brand, M.P. Genis, L.C. Hoffman, W.F.J. van de Vyver, R.Swart & G.F. Jordaan. (2013). *South African Journal of Animal Science*, 43, S140 – S145.

ABSTRACT

β-adrenergic agonists (β-AA) are commonly used in livestock production to enhance meat production and decrease the fat content of the carcass, as well as improve overall growth performance. Recent increases in meat prices and the change in consumer preference towards leaner meat have resulted in more lamb producers opting to finish leaner lambs on farms in feedlot systems. The aim of this trial was to determine the effect of dietary energy level as well as the inclusion of a β-AA on the meat quality of feedlot lambs. South African Mutton Merino, wether and ewe lambs were weaned at *ca.* 120 days of age before being randomly divided into six groups (for Experiment 1) and three groups (for experiment 2) and being adapted to each treatment. The treatments for experiment 1 consisted of three different dietary energy levels (high - 12.7 MJ ME/kg feed, medium - 12.0 MJ ME/kg feed and low - 11.3 MJ ME/kg feed) with either a β-AA agonist (Zilpaterol hydrochloride) included at 8.6 g/ton or not. Experiment 2 only consisted of three different dietary energy levels (high - 12.7 MJ ME/kg feed, medium - 12.0 MJ ME/kg feed and low - 11.3 MJ ME/kg feed). Data were analysed according to a factorial analysis. No interaction between the treatments was found for both experiments and the data was therefore presented according to the effect of dietary energy level, the inclusion of the β-adrenergic agonists and gender on the physical and proximate parameters. The inclusion of a β-adrenergic agonists and variation in dietary energy level had no effect on the proximate components, fat thickness or the tenderness of the meat. The ewes had a significant higher fat content than the ram lambs. The meat of the ram lambs was less tender than the meat from the ewe lambs.

5.1 INTRODUCTION

The most important factor influencing the consumer at the time of purchase is the colour of the meat (Kerry *et al*., 2000; Martinez-Cerezo *et al*., 2005); this obviously being in the absence of any unpleasant odours (Tejeda *et al*., 2008). Tenderness is a major factor contributing to the eating quality of the meat and consequently the consumer preference and future likelihood of purchase (Bennett, 1997; Hopkins & Fogarty, 1998; Safari *et al*., 2001).

The carcass consists primarily out of bone, muscle and fat in varying proportions (Cloete *et al*., 2004). Out of these three components the muscle is seen as the most important tissue to the consumer (Cloete *et al*., 2004). The appearance of the muscle and fat (taking the weight and classification of the carcass into consideration) determines the commercial value of lamb carcasses (Beriain *et al*., 2000). Johnson *et al*. (2005) determined the value of a lamb carcass to be dependent on the yield of lean meat. The value of the carcass is further influenced by the quality as well as the distribution of the yield of lean meat. According to Costa *et al*. (2010) the consumer market sees carcass weight as a predetermined indicator of quality.

Lamb gender influences a number of production factors such as the growth rate, body composition, feed conversion ratio (FCR) and meat quality (Rodriguez *et al*., 2008). As lambs get older the various tissue types also mature. Bone is the earliest maturing tissue, followed by meat and then fat (Rouse *et al*., 1970). The tenderness of the meat also decreases with age (Wenham *et al*., 1973).

When feeding a β-adrenergic agonist (β-AA) to livestock one typically observes an improvement in the ADG and feed efficiency (Beckett *et al*., 2009; Casey *et al*., 1997; Eckerman *et al*., 2011; Elam *et al*., 2009; Lopez-Carlos *et al*., 2010; Mersmann 2002; Montgomery *et al*., 2009; Rathmann *et al*., 2009), as well as a decrease in adipose tissue and an increase in the skeletal muscle on the carcass (Lopez-Carlos *et al*., 2010; Mersmann, 1998, 2002; Rathmann *et al*., 2009; Elam *et al*., 2009). The increase in skeletal muscle is largely due to a hypertrophic (enlargement of cells) increase in the fibre diameter of the muscles (Avendano-Reyses *et al*., 2006); an unfortunate side effect this is that the meat's tenderness may be compromised (less tender).

The aim of this study was to investigate the effect of different dietary energy levels as well as the provision of a β-adrenergic agonist on the meat quality. The effect of gender on these meat quality characteristics was also investigated.

5.2 MATERIAL AND METHODS

5.2.1 Animals and sampling

This trial was conducted in two separate experiments, in the first experiment the effect of both different energy levels (Table 5.1) as well as the inclusion of a β-AA in the diet was investigated while in the second experiment only the effect of dietary energy level was considered. In the first experiment the animals were fed a restricted diet and in the second experiment the animals were fed *ad libitum*.

Table 5.1 The formulation of the diets used in this trial

Ingredients	Diets % (As Is)		
	LE	**ME**	**HE**
Corn	44.30	54.90	65.50
Lucerne	40.00	25.90	11.80
Cottonseed Oilcake	8.00	11.45	14.89
Molasses Powder	2.500	2.50	2.50
Salt (NaCl)	1.00	1.00	1.00
Bicarbonate of Soda	1.00	1.00	1.00
Ammonium chloride	1.00	1.00	1.00
Limestone	0.90	1.10	1.30
Urea	0.50	0.50	0.50
Mono Calcium Phosphate	0.34	0.18	0.02
Vitamin & Mineral "Premix"	0.25	0.25	0.25
Sulphur	0.20	0.20	0.20
Growth promoters & Ionophores (Stafax, Tauratec & Thylan)	0.02	0.02	0.02
Total	**100**	**100**	**100**

Experiment 1

One hundred and eight South African Mutton Merino (SAMM) lambs of different genders were weaned at *ca.* 120 days of age on Langgewens Experimental Farm in the Western Cape of South Africa and finished off in a feedlot at Elsenburg Experimental Farm, Western Cape, South Africa. All the lambs were vaccinated against pulpy kidney and dosed against internal parasites on arrival at the feedlot; thereafter they were randomly allocated to pens and subjected to an adaptation period. The lambs were housed in same-gender pairs in each pen, with the size of the pens aligning to the norms described by animal welfare guidelines (ram/ewe pairs/pen).

The lambs were divided into six groups. The diets the lambs received were formulated to contain the following energy levels: diet 1 (LE) was a low energy level diet (11.3 MJ ME/kg feed), diet 2 (ME) was a medium energy level diet (12.0 MJ ME/kg feed) and diet three (HE) was a high energy level diet (12.7 MJ ME/kg feed), with each either including a β-AA or not. The β-AA (Zilpaterol hydrochloride) was included at 8.6 g/ton (recommended by Intervet) in the diet and was withdrawn from the diet 3 days prior to slaughter (Shelver & Smith, 2006). Lambs were provided with fresh clean water daily.

Experiment 2

One hundred and twenty SAMM lambs of different genders were weaned at *ca.* 120 days on Langgewens Experimental Farm in the Western Cape of South Africa and finished off under feedlot conditions (for approximately 6 weeks) at Elsenburg Experimental Farm, Western Cape, South Africa. The animals were vaccinated against pulpy kidney and external parasites on arrival at the feedlot. The lambs were housed in pens (the size of which were within the norm described by animal welfare guidelines, 117 cm x 177 cm) and randomly allocated to three groups.

The treatments consisted of three different energy level diets formulated to contain the following energy levels: diet 1 was a low energy level diet (11.3 MJ ME/kg feed), diet 2 was a medium energy level diet (12.0 MJ ME/kg feed) and diet 3 was a high energy level diet (12.7 MJ ME/kg feed). Lambs were provided with *ad libitum* feed and fresh clean water daily.

5.2.2 Proximate chemical analyses

The proximate chemical analyses were carried out on the raw *Longissimus dorsi* (LD). In experiment 1 the subcutaneous fat was not removed from the LD while for experiment 2 it was removed prior to analysis, this was due to the inclusion of the β-AA in the first experiment to see how it would affect the fat content. Homogenized samples were used for the analysis of chemical composition, with the total percentages of moisture, protein, ash and fat being determined according to AOAC methods (AOAC, 2002). The crude protein (CP) content was measured using an FP-428 Nitrogen and Protein Determinator (LECO). Lipid content (petroleum ether extraction) was measured according to AOAC methods (2002). Dry matter (DM) was determined by drying a sample (*ca.* 2.5 g) at 100^{o}C to a constant weight while ash content was determined by placing the sample in a furnace at 500^{o}C for six hours (AOAC, 2002; method 934.01 and method 942.05 respectively).

5.2.3 Instrumental analyses

The LD was used for the instrumental analyses in both experiment 1 (subcutaneous fat intact) and 2 (subcutaneous fat removed). The excised muscle was sliced into 1.5 cm thick steaks with one steak being used for the determination of drip-loss. This involved the steak first being weighed and then placed in netting and suspended in an inflated plastic bag. After a period of 24 h at 4^{o}C the sample was weighed again and the drip loss was calculated as weight loss expressed as a percentage of the original weight of the sample (Honikel, 1998).

The cooking loss determination was also done on 1.5 cm thick LD steaks. The steaks were weighed and placed in thin-walled plastic bags in a water bath at 80^{o}C. After one hour the samples were removed from the water bath, cooled, blotted dry and weighed. Cooking loss was calculated as the difference in sample weight before and after cooking, expressed as a percentage of the initial sample weight (Honikel, 1998).

The cooked meat samples used for cooking loss determination were then used to determine the tenderness of the meat. The tenderness was measured using a Warner-Bratzler device, with a load of 2.000 kN, attached to an Instron (Model 4444) Testing Instrument. Three cylindrical core samples (1.27 cm diameter) were cut from each cooked piece of muscle (thus three pieces from each lamb) at random locations on the cooked steak. Maximum Warner-Bratzler shear force values were recorded by shearing the cylindrical core of cooked muscle perpendicular to the longitudinal orientation of the muscle fibres at a crosshead speed of 200 mm/min. An average shear force value (N) was then calculated for each lamb. Care was taken to avoid cylindrical core samples that contained visible connective tissue that could have an influence on the shear force results.

The meat samples used to determine the colour of the meat were allowed to bloom for 30 minutes at room temperature (18-19^{o}C) before a colour reading was recorded according to the method described by Honikel (1998). Colour was measured by a colour guide (BYK Gardner, USA), the CIElab colour scale.

5.2.4 Statistical analyses

Experiment 1

The experiment consisted of a completely randomised design with six treatments (dietary energy level with or without a β-AA). The treatment design was a 3x2x2 factorial with dietary energy level (low, medium and high), the provision of a β-AA (included or absent) and gender (rams and ewes) as the main factors.

A factorial analysis of variance was performed on the data using SAS for Windows Version 9.1.3 Proc GLM (SAS, 2000), whereas normality was tested with the Shapiro-Wilk test (Shapiro & Wilk, 1965). Outliers were removed, which caused deviations from normality, prior to the final analyses. Student's t-Least Significant Difference (LSD) was calculated at the 5% significance level to compare treatment means.

Experiment 2

This experiment consisted of a completely randomised design with three treatments (dietary energy level). The treatment design was a 3 x 2 factorial with dietary energy level (low, medium and high) and gender (wethers and ewes) as the main factors.

A factorial analysis of variance was performed on the data using SAS for Windows Version 9.1.3 (SAS, 2000), whereas normality was tested with the Shapiro-Wilk test (Shapiro & Wilk, 1965). Outliers causing a deviation from a normal distribution were removed prior to the final statistical analysis.

5.3 RESULTS

Experiment 1

No interaction between the main factors was found in any of the data from Experiment 1, thus allowing the treatments to be interpreted separately. Neither the physical nor the proximate parameters were affected by the dietary energy level; refer to Tables 5.2 and 5.3 for these results.

Table 5.2 Least square means (± s.e.) depicting the effect of dietary energy level on the physical meat quality characteristics of SAMM feedlot lambs

Physical Parameters	LE	ME	HE	P-Value
pH_{45}	$6.70^a \pm 0.04$	$6.56^a \pm 0.05$	$6.71^a \pm 0.05$	0.055
pH_{48}	$5.68^a \pm 0.05$	$5.64^a \pm 0.05$	$5.69^a \pm 0.05$	0.689
Drip loss (%)	$0.8^a \pm 0.04$	$0.8^a \pm 0.04$	$0.8^a \pm 0.04$	0.608
Cooking loss (%)	$17.3^a \pm 0.83$	$17.1^a \pm 0.84$	$16.6^a \pm 0.83$	0.825
L*	$36.19^a \pm 0.48$	$35.24^a \pm 0.50$	$36.89^a \pm 0.49$	0.069
a*	$12.81^a \pm 0.26$	$13.64^a \pm 0.26$	$13.41^a \pm 0.26$	0.075
b*	$10.79^a \pm 0.28$	$10.51^a \pm 0.29$	$11.00^a \pm 0.29$	0.489
Tenderness (N)	$63.50^a \pm 1.93$	$59.31^a \pm 1.99$	$59.33^a \pm 1.95$	0.226
Fat thickness caudal (mm)	$7.55^a \pm 0.43$	$8.61^a \pm 0.44$	$8.15^a \pm 0.43$	0.395
Fat thickness cranial (mm)	$8.53^a \pm 0.50$	$7.57^a \pm 0.51$	$8.28^a \pm 0.50$	0.243

[a,b] Row means with different superscripts differ significantly ($P \leq 0.05$)

L^*, a^* & b^* are the colour coordinates of meat

Table 5.3 Least square means (± s.e.) depicting the effect of dietary energy level on the proximate meat quality characteristics of SAMM feedlot lambs

Proximate Parameters	LE	ME	HE	P-Value
Moisture (%)	$56.4^a \pm 1.19$	$57.9^a \pm 1.23$	$55.6^a \pm 1.21$	0.404
Dry Matter (%)	$43.7^a \pm 1.19$	$42.1^a \pm 1.23$	$44.4^a \pm 1.21$	0.404
Protein (%)	$14.4^a \pm 1.08$	$12.4^a \pm 1.12$	$12.9^a \pm 1.10$	0.424
Fat (%)	$24.0^a \pm 1.57$	$24.9^a \pm 1.62$	$27.6^a \pm 1.59$	0.260
Ash (%)	$1.7^a \pm 0.32$	$2.7^a \pm 0.33$	$2.1^a \pm 0.33$	0.121

[a,b] Row means with different superscripts differ significantly ($P \leq 0.05$)

Neither the physical nor the proximate parameters were affected by the inclusion of the β-AA in the diet; refer to Tables 5.4 and 5.5 for these results.

Table 5.4 Least square means (± s.e.) depicting the effect of the inclusion of a β-AA on the physical meat quality characteristics of SAMM feedlot lambs

Physical Parameters	β-AA		
	Absent	Included	P-Value
pH_{45}	6.70[a] ± 0.04	6.61[a] ± 0.04	0.071
pH_{48}	5.62[a] ± 0.04	5.73[a] ± 0.04	0.061
Drip loss (%)	0.8[a] ± 0.03	0.8[a] ± 0.04	0.889
Cooking loss (%)	17.4[a] ± 0.68	16.7[a] ± 0.68	0.473
L*	36.59[a] ± 0.40	35.63[a] ± 0.40	0.094
a*	13.49[a] ± 0.21	13.09[a] ± 0.21	0.190
b*	10.97[a] ± 0.23	10.57[a] ± 0.23	0.237
Tenderness (N)	59.84[a] ± 1.58	61.58[a] ± 1.60	0.443
Fat thickness caudal (mm)	8.46[a] ± 0.35	7.75[a] ± 0.35	0.417
Fat thickness cranial (mm)	8.36[a] ± 0.41	7.89[a] ± 0.41	0.158

[a,b] Row means with different superscripts differ significantly (P ≤ 0.05)

Table 5.5 Least square means (± s.e.) depicting the effect of the inclusion of a β-AA on the proximate meat quality characteristics

Proximate Parameters	β-AA		
	Absent	Included	P-Value
Moisture (%)	56.8[a] ± 0.98	56.4[a] ± 0.99	0.759
Dry matter (%)	43.2[a] ± 0.98	43.6[a] ± 0.99	0.758
Protein (%)	13.8[a] ± 0.89	12.6[a] ± 0.90	0.323
Fat (%)	24.8[a] ± 1.29	26.2[a] ± 1.30	0.440
Ash (%)	2.5[a] ± 0.26	1.8[a] ± 0.27	0.057

[a,b] Row means with different superscripts differ significantly (P ≤ 0.05)

The gender of the lambs significantly affected some of the physical (pH_{48} and tenderness; Table 5.6) and proximate (fat, moisture and dry material; DM; Table 5.7) parameters of the meat.

Table 5.6 Least square means (± s.e.) depicting the effect of gender on the physical meat quality characteristics of SAMM feedlot lambs

Physical Parameters	Gender		
	Ewe	Ram	P-Value
pH_{45}	$6.66^{a} \pm 0.10$	$6.66^{a} \pm 0.07$	0.067
pH_{48}	$5.59^{a} \pm 0.04$	$5.75^{b} \pm 0.04$	0.008
Drip loss (%)	$0.8^{a} \pm 0.04$	$0.8^{a} \pm 0.03$	0.779
Cooking loss (%)	$16.3^{a} \pm 0.71$	$17.7^{a} \pm 0.65$	0.154
L*	$35.92^{a} \pm 0.43$	$36.29^{a} \pm 0.39$	0.533
a*	$13.49^{a} \pm 0.22$	$13.09^{a} \pm 0.20$	0.200
b*	$11.07^{a} \pm 0.25$	$10.47^{a} \pm 0.23$	0.082
Tenderness (N)	$57.82^{a} \pm 1.69$	$63.60^{b} \pm 1.54$	0.016
Fat thickness caudal (mm)	$8.47^{a} \pm 0.37$	$7.74^{a} \pm 0.34$	0.139
Fat thickness cranial (mm)	$8.58^{a} \pm 0.43$	$7.68^{a} \pm 0.40$	0.161

^{a,b} Row means with different superscripts differ significantly ($P \leq 0.05$)

The ram lambs had a significantly higher pH_{48} (the pH measured 48 h after slaughter; 5.75 ± 0.04) than the ewes (5.59 ± 0.04). The ewe lambs' meat was significantly more tender than the meat from the.

Table 5.7 Least square means (± s.e.) depicting the effect of gender on the proximate meat quality characteristics of SAMM feedlot lambs

Proximate	Gender		
Parameters	Ewe	Ram	P-Value
Moisture (%)	$54.2^{a} \pm 1.04$	$59.0^{b} \pm 0.95$	0.001
Dry matter (%)	$45.8^{a} \pm 1.04$	$41.0^{b} \pm 0.95$	0.001
Protein (%)	$12.8^{a} \pm 0.95$	$13.7^{a} \pm 0.87$	0.484
Fat (%)	$27.9^{a} \pm 1.38$	$23.1^{b} \pm 1.26$	0.014
Ash (%)	$2.4^{a} \pm 0.28$	$2.0^{a} \pm 0.26$	0.292

^{a,b} Row means with different superscripts differ significantly ($P \leq 0.05$)

The ewes (27.9 ± 1.38) had a significantly higher fat percentage in the carcass than the ram (23.1 ± 1.26) lambs. Meat from rams (59.02 ± 0.95) had a higher moisture content than that from ewes (54.2 ± 1.04), whereas the ewe (45.8 ± 1.04) lambs had a higher DM percentage in the carcass than the rams (41.0 ± 0.95).

Experiment 2

No interactions between the main factors were recorded; allowing the data to be interpreted separately. Of the physical parameters, only drip loss was affected by the dietary energy level (see Table 5.8). None of the proximate parameters were affected by the dietary energy level (see Table 5.9).

Table 5.8 Least square means (± s.e.) depicting the effect of dietary energy level on the physical meat quality characteristics of SAMM feedlot lambs

Physical Parameters	LE	ME	HE	P-Value
pH_{45}	$5.58^{a} \pm 0.07$	$5.59^{a} \pm 0.07$	$5.65^{a} \pm 0.08$	0.788
pH_{48}	$5.60^{a} \pm 0.02$	$5.59^{a} \pm 0.02$	$5.65^{a} \pm 0.03$	0.422
Drip loss (%)	$1.3^{a} \pm 0.09$	$1.4^{a,b} \pm 0.09$	$1.1^{a,c} \pm 0.10$	0.036
Cooking loss (%)	$32.9^{a} \pm 0.46$	$32.6^{a} \pm 0.46$	$31.7^{a} \pm 0.52$	0.204
L*	$39.31^{a} \pm 0.44$	$39.12^{a} \pm 0.44$	$37.83^{a} \pm 0.49$	0.057
a*	$13.23^{a} \pm 0.20$	$13.29^{a} \pm 0.20$	$13.70^{a} \pm 0.22$	0.245
b*	$10.72^{a} \pm 0.21$	$10.50^{a} \pm 0.21$	$10.23^{a} \pm 0.23$	0.298
Tenderness (N)	$44.71^{a} \pm 2.42$	$45.27^{a} \pm 2.42$	$45.44^{a} \pm 2.71$	0.977
Fat thickness caudal (mm)	$7.15^{a} \pm 0.37$	$6.34^{a} \pm 0.37$	$6.45^{a} \pm 0.41$	0.276
Fat thickness cranial (mm)	$5.08^{a} \pm 1.37$	$4.99^{a} \pm 1.39$	$7.93^{a} \pm 1.50$	0.403

[a,b] Row means with different superscripts differ significantly ($P \leq 0.05$)

The drip loss of the meat of the lambs on the medium energy diet (1.4 ± 0.09%) differed significantly from the drip loss of the lambs on the high energy diet (1.1 ± 0.10%). The percentage drip loss of the lambs on the ME diet was the highest with the loss of those on the HE diet the lowest. No significant differences were found in the drip loss percentage between the lambs on the low energy diet (1.3 ± 0.09%) and the other two diets.

Table 5.9 Least square means (± s.e.) depicting the effect of dietary energy level on the proximate meat quality characteristics of SAMM feedlot lambs

Proximate Parameters	LE	ME	HE	P-Value
Moisture (%)	$72.2^{a} \pm 0.50$	$72.5^{a} \pm 0.50$	$72.5^{a} \pm 0.55$	0.790
Dry Matter (%)	$27.9^{a} \pm 0.50$	$27.5^{a} \pm 0.50$	$27.5^{a} \pm 0.55$	0.790
Protein (%)	$19.9^{a} \pm 0.37$	$19.5^{a} \pm 0.38$	$19.5^{a} \pm 0.41$	0.628
Fat (%)	$5.9^{a} \pm 0.32$	$6.0^{a} \pm 0.33$	$5.8^{a} \pm 0.35$	0.932
Ash (%)	$1.1^{a} \pm 0.03$	$1.0^{a} \pm 0.03$	$1.0^{a} \pm 0.03$	0.281

[a,b] Row means with different superscripts differ significantly ($P \leq 0.05$)

Gender had no effect on either the physical or proximate parameters (refer to Tables 5.10 and 5.11).

Table 5.10 Least square means (± s.e.) depicting the effect of gender on the physical meat quality characteristics of SAMM feedlot lambs

Physical Parameters	**Gender**		
	Ewe	**Wether**	**P-Value**
pH_{45}	$5.85^{a} \pm 0.06$	$5.63^{a} \pm 0.06$	0.555
pH_{48}	$5.60^{a} \pm 0.02$	$5.62^{a} \pm 0.02$	0.972
Drip loss (%)	$1.3^{a} \pm 0.07$	$1.2^{a} \pm 0.08$	0.558
Cooking loss (%)	$32.6^{a} \pm 0.39$	$32.2^{a} \pm 0.40$	0.490
L*	$38.97^{a} \pm 0.36$	$38.54^{a} \pm 0.38$	0.409
a*	$13.39^{a} \pm 0.17$	$13.43^{a} \pm 0.17$	0.883
b*	$10.53^{a} \pm 0.18$	$10.43^{a} \pm 0.18$	0.706
Tenderness (N)	$47.55^{a} \pm 2.02$	$42.73^{a} \pm 2.09$	0.101
Fat thickness caudal (mm)	$6.58^{a} \pm 0.31$	$6.92^{a} \pm 0.32$	0.544
Fat thickness cranial (mm)	$6.50^{a} \pm 1.14$	$5.50^{a} \pm 1.18$	0.441

[a,b] Row means with different superscripts differ significantly ($P \leq 0.05$)

Table 5.11 Least square means (± s.e.) depicting the effect of gender on the proximate meat quality characteristics of SAMM feedlot lambs

Proximate Parameters	Gender		
	Ewe	Wether	P-Value
Moisture (%)	$72.2^{a} \pm 0.39$	$72.5^{a} \pm 0.45$	0.125
Dry matter (%)	$27.8^{a} \pm 0.39$	$27.5^{a} \pm 0.45$	0.125
Protein (%)	$19.7^{a} \pm 0.30$	$19.5^{a} \pm 0.34$	0.811
Fat (%)	$5.8^{a} \pm 0.25$	$6.0^{a} \pm 0.29$	0.075
Ash (%)	$1.0^{a} \pm 0.02$	$1.0^{a} \pm 0.02$	0.763

[a,b] Row means with different superscripts differ significantly ($P \leq 0.05$)

5.4 DISCUSSION

The higher pHu of the rams can be contributed to the more active nature of rams. Devine *et al*. (1993) found that the pHu is an important meat quality indicator and that pH values higher than 5.8 are undesirable due to the resulting dark, firm and dry (DFD) condition of the meat (Gardner *et al*., 1999). The differences observed may also be as a result of the lambs being under mild nutritional stress due to a restricted diet of the first experiment and different nutritional requirements of ewe and ram lambs.

The tenderness of the meat is influenced by four major factors: age, cold shortening, stress and the cut of the meat (Spooncer *et al*., 2000). The quality of the meat can therefore be improved by selection of pastures/diet (both selected by the animal and planted), better pre-slaughter handling and carcass processing. The age of the animal affects tenderness primarily through its influence on the amount and solubility of the connective tissue present in the meat (Spooncer *et al*., 2000). According to Spooncer *et al*. (2000) there will also be differences in tenderness between the various muscles of the same carcass, for example the loin muscle (*Longissimus dorsi*, LD) is generally more tender than the leg muscles (e.g. *Semimembranosus*; SM and *Semitendinosus*; ST). The hindquarter cuts are also typically tenderer than the forequarter cuts (Spooncer *et al*., 2000); this is in accordance with Wolf *et al*. (2001) and Johnson *et al*. (2005) who found that rams were better developed in the forequarters while ewe lambs better developed in the hindquarters.

The ewes had a significantly higher fat percentage in the carcass than the ram lambs. Fat is a late maturing tissue (Thu, 2006), while the ewe is an early maturing animal (Butterfield, 1988); the ewe will therefore fatten up earlier than the rams and the carcass will contain a higher fat percentage.

The meat from the rams had a higher moisture content than that from ewes; whereas the ewe (45.8 ± 1.04) lambs had a higher DM percentage in the carcass than the rams (41.0 ± 0.95). This confirms with Craigie *et al*. (2012), where it was found that ram lamb meat had a significantly ($P<0.05$) higher moisture content than meat from ewes.

The lambs, in the second experiment, on the high dietary energy level had the lowest drip loss and therefore a higher water holding capacity (WHC), this in agreement with the results of Abd El-aal & Suliman (2008). However in contrast to the findings of the present study the results of Abd El-aal & Suliman (2008) indicated that both the highest and lowest dietary energy levels resulted in meat with a higher water holding capacity than that from sheep fed the intermediate energy level diet.

5.5 CONCLUSIONS

The dietary energy levels did not affect any of the meat attributes accept for drip loss in the second experiment. The lambs on the HE had the lowest drip loss. Therefore the high dietary energy level (12.7 MJ ME/kg feed) had juicier meat compared to the meat of the lambs on the LE and ME diet.

The low inclusion levels of β-AA had no significant effect on either the physical or proximate chemical parameters of the meat. Further research into the use of higher inclusion levels of the β-AA is recommended in order to determine at what inclusion level the fat content of the carcass is reduced. Montgomery *et al*. (2008) fed 8.3 mg/kg (DM basis) to beef steers and succeeded in reducing the 12-rib fat thickness. However Avendano-Reyes *et al*. (2011) fed 10 mg ZH/ewe/day, and found it to have no effect on the fat thickness of the carcass. It is therefore recommended to include the β-AA at higher inclusion levels for commercial production of lambs.

When examining the effect of gender on meat quality attributes it was concluded from the two experiments that there is no significant difference between ewes and wethers; however there are significant differences between the meat attributes of ewes and rams.

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CHAPTER 6

THE EFFECT OF DIETARY ENERGY AND THE USE OF A β-AGONIST ON THE SENSORY, PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE MEAT OF SOUTH AFRICAN MUTTON MERINO FEEDLOT LAMBS

ABSTRACT

The acceptability of meat is dependent on the toughness (chewiness and resistance), flavour (aroma and taste) and succulence (juiciness) of the meat. It is known that the dietary energy content as well as the inclusion of a β-adrenergic agonist in the feed may influence the sensory, physical and chemical characteristics of meat. To quantify the effect of these two parameters, 108 South African Mutton Merino lambs, weaned at *ca.* 120 days of age and of different genders, were housed in individual pens for approximately six weeks (40 days). The treatments consisted of two different dietary energy levels (HE – 12.7 MJ/ME/kg feed; LE – 11.3 MJ/ME/kg feed) with either the inclusion or absence of a β-adrenergic agonist (Zilpaterol hydrochloride, 8.6 g/ton) in the diet. The experimental design was a 2 x 2 x 2 factorial design with gender, inclusion of a β-adrenergic agonist and dietary energy content as main factors. No significant differences (P>0.05) due to dietary energy level or the inclusion of the β-antagonist were found for the physical characteristics of the meat. Significant ($P\leq0.05$) differences in tenderness between genders (76.2% for ewes vs. 72.9% for rams), as well as between the two β-agonist treatments (75.4% vs. 72.9% for the inclusion of the β-antagonist), were however found during the sensory testing. Sustained juiciness was also affected (P<0.05) by gender (68.0% for ewes vs. 65.7% for rams) and the inclusion of a β-agonist (67.9% absent vs. 65.8% included). Overall it was concluded that, of all three main effects, gender affected the meat attributes most significantly.

6.1 INTRODUCTION

The acceptability of meat for the consumer is dependent on its toughness (chewiness and resistance), flavour and succulence or juiciness (Hoffman *et al*., 2003). The tenderness of lamb's meat generally decreases with age (Wenham *et al*., 1973), whereas the animal flavour intensifies (Sink & Caporaso, 1977).

Martinez-Cerezo *et al*. (2005) concluded that consumers from the Mediterranean countries preferred the meat from lighter lambs. These consumers believe that the meat from lighter lamb carcasses is of a higher quality – with this being signified by a lower flavour intensity and greater tenderness relative to that from heavier carcasses. Tejeda *et al*. (2008) also concluded that the meat from heavier lambs (which is less tender and has a more intense flavour) is considered to be of a lower quality than that from lighter lambs.

The use of a β-adrenergic agonist (β-AA) in livestock feed typically increases the ADG and improves feed efficiency (Beckett *et al*., 2009; Casey *et al.,* 1997; Eckerman *et al*., 2011; Elam *et al*., 2009; Lopez-Carlos *et al*., 2010; Mersmann 2002; Montgomery *et al*., 2009; Rathmann *et al*., 2009), as well as decreasing adipose tissue deposition and increasing skeletal muscle (Lopez-Carlos *et al*., 2010; Mersmann, 1998, 2002; Rathmann *et al*., 2009). The increase in skeletal muscle mass is largely due to a hypertrophic (enlargement of cells) increase in the fibre diameter of the muscles (Avendano-Reyses *et al*., 2006), with an unfortunate side effect of this being a compromise in meat tenderness. It was found by Hilton *et al*. (2009) that the use of Zilpaterol hydrochloride (ZH) decreases the sensory tenderness rating of beef and increases the shear force (Leheska *et al*., 2009).

Although the use of β-AA in beef diets has been approved and there is a number of scientific reports documenting the effect thereof on meat quality, the use thereof in sheep is limited. The aim of this study was therefore to investigate the effect of different levels of dietary energy, as well as the inclusion of a β-AA, on the sensory, physical and chemical characteristics of meat from South African Mutton Merino lambs.

6.2 MATERIAL AND METHODS

6.2.1 Animals and sampling

One hundred and eight South African Mutton Merino lambs were weaned at *ca.* 120 days of age on Langgewens Experimental Farm in the Western Cape of South Africa. They were subsequently transported to the experimental site: Elsenburg Experimental Farm, Western Cape, South Africa. On arrival the lambs were allocated to pens, with each pen being randomly assigned to one of four different treatments (Table 6.1). The treatments were as follows: diet 1 (LE with β-AA)was a low energy level diet (11.3 MJ ME/kg feed) with a β-adrenergic agonist (β-AA), diet 2 (LE) was a low energy level diet (11.3 MJ ME/kg feed) without a β-AA, diet 3 (HE with β-AA) was a high energy level diet (12.7 ME MJ/kg feed) with a β-AA and diet 4 (HE) was a high energy level diet (12.7 MJ ME/kg feed) without a β-AA. The β-AA was included in the diet at 8.6 g/ton feed. The β-AA was withdrawn from the diet three days prior to slaughter (Shelver & Smith, 2006).

Table 6.1 Low and high energy diets provided to the 108 SAMM lambs with or without the β-AA

Ingredients	Diets % (As Is)	
	Low energy diet	**High energy diet**
Maize	44.30	65.50
Lucerne	40.00	11.80
Cottonseed Oilcake	8.00	14.89
Molasses Powder	2.500	2.50
Salt (NaCl)	1.00	1.00
Bicarbonate of Soda	1.00	1.00
Ammonium Chloride	1.00	1.00
Limestone	0.90	1.30
Urea	0.50	0.50
Mono Calcium Phosphate	0.34	0.02
Vitamin & Mineral "Premix"	0.25	0.25
Sulphur	0.20	0.20
Growth promoters & Ionofores (Stafax, Tauratec & Thylan)	0.02	0.02
Total	**100**	**100**

The lambs were deliberately grown to a higher weight (± 54 kg) than the average commercial lamb slaughter weight (± 40 kg) in South Africa in order to determine whether and how the β-AA would affect the carcass composition. The lambs were transported from Elsenburg experimental farm to a registered sheep abattoir (Roelcor, in Malmesbury, Western Cape, South Africa) the day prior to slaughter. The lambs were slaughtered using standard South African techniques, with no electrical stimulation being applied (Cloete *et al*., 2008). The pH of the carcasses was measured 45 minutes after slaughter, just before the carcasses were placed in the cooling unit for 48 hours. The pH was measured between the 2nd and 3rd last thoracic vertebrae. The ultimate pH was measured 48 hours after slaughter, in the same the position as that measured the day of slaughter.

After the carcasses had been weighed the *M. longissimus dorsi* was removed for the measurements of drip loss, cooking loss, colour and tenderness. The right hind leg of each carcass was removed, vacuum packed and frozen at -20ºC until further analysis. The *M. semimembranosus* (SM) and the *M. semitendinosus* (ST) were excised from each leg and thawed. The *M. semimembranosus* were used for sensory analysis and the *M. semitendinosus* were used for proximate analyses.

6.2.2 Sensory analysis

The right leg was defrosted at a temperature of 3-4ºC over a period of 48 hours. The legs were then placed on a flat surface with the lateral side facing upwards. An incision was made on the septa, followed by an incision at the top end, cutting as close to the pelvic bone as possible. The natural division between the muscles then became visible and the *M. semimembranosus* could be separated from the other muscles by cutting along the connective tissue membrane between the muscles. After its removal the *M. semimembranosus* was vacuumed packed, frozen and stored until further analyses could be done.

The *M. semimembranosus* meat samples were defrosted over 36 hours at a temperature of 3-4ºC prior to the day of the sensory analysis. After removal from the vacuum packaging, two steaks were cut from each muscle and placed inside marked oven bags (GLAD™). The two steaks were treated as one entity and placed together inside one bag. No seasoning was added to any of the meat treatments throughout the sensory training or analysis process. The roasting bags with the meat samples were then placed on a stainless steel grid, which was fitted onto an oven roasting pan. Two conventional electric Defy 835 ovens preheated to 160ºC were used to roast the samples. The ovens were connected to a computerised electronic temperature control system (Viljoen *et al*., 2001). A thermocouple attached to a handheld digital temperature monitor was inserted into the centre of each sample (Hanna Instruments South Africa) and the meat was roasted to an internal temperature of 70ºC (AMSA, 1978).

Once the meat samples had reached the required internal temperature a ten minute cooling period was allowed for each sample. All visible subcutaneous fat was then removed from each sample before it was cut into the necessary sampling cubes. Cubes of 1.5 x 1.5 x 1.5 cm were cut from each sample and wrapped in aluminium foil marked with random three digit codes. The wrapped cubes were placed in glass ramekins. The coded ramekins, each containing two wrapped cubes, were then placed into an oven preheated to 100ºC for 10 minutes, after which they were removed and immediately served to the panel for analysis. Descriptive sensory analysis was performed on the meat.

Nine panellists were selected and trained in accordance with the AMSA guidelines for the sensory evaluation of meat (AMSA, 1978). They were exposed to the various meat samples and the tasting procedure in two preliminary training sessions. The nine-member panel evaluated the meat for the following sensory attributes: aroma intensity, initial impression of juiciness, sustained juiciness, tenderness, mealiness, residue, overall lamb flavour and atypical flavour. The attributes, the scale thereof and the definitions or descriptions are summarized in Table 6.2.

Table 6.2 Definition of attributes and the scale of evaluations for the sensory analyses of lamb meat

Attribute	**Definition**
Lamb Aroma 10 = Extremely bland; 100 = Extremely intense	Aroma associated with the animal species
Initial Impression of Juiciness 10 = Extremely dry; 100 = Extremely juicy	The amount of fluid exuded on the cut surface when pressed between fingers
Sustained Juiciness 10 = Extremely dry; 100 = Extremely juicy	Amount of fluid perceived during mastication
First Bite 10 = Extremely tough; 100 = Extremely tender	The impression of tenderness after the first two to three chews between the molar teeth
Mealiness 10 = Extremely firm; 100 = Extremely mealy	The disintegration of the sample during mastication, resulting in a mealy texture
Residue 10 = Abundant; 100 = None	The connective tissue remaining after most of the sample has been masticated
Overall Lamb Flavour 10 = Extremely typical; 100 = Extremely untypical	Flavour associated with the animal species
Atypical Flavour 10 = Extremely typical; 100 = Extremely untypical	Flavour not typically associated with lamb

(Schmidt, 2002)

The panellists were seated within individual booths in a temperature- and light-controlled room. The panellists received a set of eight samples which were served in a completely random order. Crackers and distilled water were provided to cleanse the palate between samples (AMSA, 1978).

6.2.3 Proximate chemical analyses

Proximate chemical analyses were carried out on the raw *M. semitendinosus* from the right leg after the removal of the subcutaneous fat. Total percentages of moisture, protein and ash were determined according to AOAC methods (AOAC, 2002). The samples were homogenised, freeze-dried (Virtis benchtop K), ground (Knifetec 1095 Sample Mill) and analysed for chemical composition. The crude protein (CP) was measured using a FP-428 Nitrogen and Protein Determinator (LECO). Lipid content (petroleum ether extraction) was measured according to the standard AOAC (2002) method. Dry matter (DM) was determined by drying a sample (*ca.* 2.5 g) at 100ºC to a constant weight, and ash content by placing the sample in a furnace at 500ºC for six hours (AOAC, 2002; method 934.01 and method 942.05 respectively).

6.2.4 Instrumental analyses

For the instrumental analyses the *M. longissimus dorsi* was used. This muscle was removed from the carcass 48 h after slaughter, placed in plastic bags and transported to the laboratory. On arrival at the laboratory the muscles were cut up into 1.5 cm thick steaks. One of these slices was used for drip loss. This involved the steak being weighed and then suspended in a plastic bag filled with air over a period of 24 h at 4ºC. After the storage period the steak was removed from the plastic bag, blotted dry with tissue paper and weighed again. The drip loss was calculated as the change in the weight of the steak over the storage period. This was expressed as a percentage of the original weight of the steak as determined prior to the storage period (Honikel, 1998).

Another steak from the *M. longissimus dorsi* was used for cooking loss determination. The sample was weighed and placed in a plastic bag in a water bath preheated to 80ºC for one hour. After an hour the sample was removed from the water bath, cooled down, blotted dry and weighed. The cooking loss was calculated as the weight loss of the sample during cooking. The calculated cooking loss was expressed as a percentage of the initial sample weight (Honikel, 1998).

The remainder of the raw *M. longissimus dorsi* was left for 30 minutes at room temperature (19ºC) before colour readings were taken (Honikel, 1998). The colour measurements were taken in triplicate at randomly selected positions on the steak. A Colour-guide (BYK-Gardner, USA) was used to determine the coordinates of the CIElab colorimetric space L*, a* and b* (Minolta, 1998). The L* coordinate is an indication of the lightness, the a* coordinate an indication of the red-green range and the b* coordinate an indication of the blue-yellow range of the meat.

The instrumental tenderness of the meat was determined by measuring the shear force of the cooked sample used for the calculation of cooking loss. These measurements were obtained using a Warner-Bratzler shear force (WBSF) attachment (Voisey, 1976), fitted to an Instron texture determination instrument (model 4444). The Instron instrument had a measuring speed of 200.0 mm/min. Shear force measurements were taken across the fibre grain for three cores of 1.27 cm in diameter cut from each sample perpendicular to the grain, with the mean of the three cores being used for statistical analysis.

6.2.5 Statistical analyses

The samples used for sensory analysis were compared according to treatment. These treatments consisted of either receiving a low or high dietary energy level, with or without the inclusion of a β-adrenergic agonist (β-AA), with gender also being considered as a main factor. The sensory scores were transformed into ranks prior to the analysis of variance.

A factorial analysis of variance was performed on the data using SAS for Windows Version 9.2 Proc. GLM (SAS, 2000); whereas normality was tested using the Shapiro-Wilk test (Shapiro & Wilk, 1965). Outliers causing deviations from normality were removed before final analysis. Student's t-Least Significant Differences (LSD) were calculated at the 5% significance level to enable the comparison of individual treatment means.

6.3 RESULTS

Apart from for the overall lamb flavour, DM % and fat % no interaction among the other measured characteristics was found, thus enabling the separate interpretation of the main effects. The interaction between the β-AA and gender for overall lamb flavour (Table 6.12), as well as the interaction between gender, β-AA and dietary energy content for DM % and fat % (Table 6.13), are also discussed later.

The lamb aroma intensity was the only sensory characteristic affected by the dietary energy level (Table 6.3). Neither physical nor chemical parameters were influenced by the dietary energy level (refer to Tables 6.4 and 6.5).

Table 6.3 Least square means (± s.e.) depicting the effect of dietary energy on the sensory characteristic parameters of the *M. semimembranosus* of SAMM lambs

Sensory Parameters	LE	HE	P-Value
Lamb aroma intensity	$78.7^{a} \pm 0.64$	$76.2^{b} \pm 0.64$	0.009
Initial juiciness	$74.3^{a} \pm 0.88$	$75.1^{a} \pm 0.88$	0.559
Sustained juiciness	$66.3^{a} \pm 0.80$	$67.7^{a} \pm 0.80$	0.231
Tenderness	$73.5^{a} \pm 1.23$	$74.1^{a} \pm 1.23$	0.762
Mealiness	$6.1^{a} \pm 0.71$	$6.3^{a} \pm 0.71$	0.899
Residue	$7.7^{a} \pm 0.62$	$7.3^{a} \pm 0.62$	0.619
Overall lamb flavour	$78.9^{a} \pm 0.43$	$78.1^{a} \pm 0.43$	0.214
Atypical flavour	$1.2^{a} \pm 0.39$	$2.3^{a} \pm 0.39$	0.060

^{a,b} Row means with different superscripts differ significantly ($P \leq 0.05$)

Meat from the lambs on the low dietary energy level had a higher lamb aroma intensity than that from the lambs on the high dietary energy level.

Table 6.4 Least square means (± s.e.) depicting the effect of dietary energy level on the physical parameters of the *M. longissimus dorsi* of SAMM lambs

Physical Parameters	LE	HE	P-Value
Drip loss (%)	$0.9^{a} \pm 0.05$	$0.8^{a} \pm 0.06$	0.320
Cooking loss (%)	$16.3^{a} \pm 0.98$	$17.1^{a} \pm 1.03$	0.580
L*	$36.2^{a} \pm 0.61$	$34.81^{a} \pm 0.64$	0.108
a*	$13.00^{a} \pm 0.26$	$13.23^{a} \pm 0.28$	0.566
b*	$10.67^{a} \pm 0.36$	$10.46^{a} \pm 0.38$	0.698
Tenderness (N)	$58.50^{a} \pm 4.29$	$61.28^{a} \pm 4.51$	0.659

^{a,b} Row means with different superscripts differ significantly ($P \leq 0.05$)

L^{*}, a^{*} & b^{*} are the colour coordinates measured in the meat to evaluate the colour of the meat

Table 6.5 Least square means (± s.e.) depicting the effect of the dietary energy level on the chemical parameters of *M. semitendinosus* of SAMM lambs

Chemical Parameters	LE	HE	P-Value
Dry matter (%)[#]	26.7 ± 0.42	26.7 ± 0.44	0.953
Protein (%)	19.3^a ± 0.33	19.1^a ± 0.35	0.718
Fat (%)#	5.3 ± 0.31	5.3 ± 0.31	0.918
Ash (%)	1.1^a ± 0.02	1.1^a ± 0.04	0.472

^{a,b} Row means with different superscripts differ significantly ($P \leq 0.05$)

[#]Due to interaction main effects cannot be interpreted

Of the sensory parameters, sustained juiciness and tenderness were the only descriptive traits affected by the inclusion of the β-AA, the rest of the parameters were not affected (Table 6.6). Neither the physical nor the chemical parameters were affected by the inclusion of the β-AA (refer to Tables 6.7 and 6.8).

Table 6.6 Least square means (± s.e.) depicting the effect of the inclusion of a β-AA on the sensory parameters of *M. semimembranosus* of SAMM lambs

Sensory Parameters	β-AA		
	Absent	Included	P-Value
Lamb aroma intensity	76.9^a ± 0.64	78.0^a ± 0.64	0.234
Initial juiciness	75.6^a ± 0.88	73.8^a ± 0.88	0.172
Sustained juiciness	67.9^a ± 0.63	65.8^b ± 0.63	0.043
Tenderness	75.4^a ± 0.83	72.9^b ± 0.83	0.024
Mealiness	6.4^a ± 0.71	6.1^a ± 0.71	0.773
Residue	7.2^a ± 0.62	7.8^a ± 0.62	0.498
Overall lamb flavour[#]	78.7 ± 0.43	78.4 ± 0.43	0.586
Atypical flavour	1.8^a ± 0.39	1.7^a ± 0.39	0.839

^{a,b} Row means with different superscripts differ significantly ($P \leq 0.05$)

[#]Due to interaction main effects cannot be interpreted

The meat samples from the lambs that did receive the β-AA had a higher sustained juiciness than those from the lambs from the group that did not receive the β-AA). The meat samples from the lambs that did not receive the β-AA (75.35 ± 0.83) were more tender than those from the lambs that did receive the β-AA (72.92 ± 0.83).

Table 6.7 Least square means (± s.e.) depicting the effect of the β-AA on the physical parameters of *M. longissimus dorsi* of SAMM lambs

Physical Parameters	**β-AA**		
	Absent	**Included**	**P-Value**
Drip loss (%)	$0.8^{a} \pm 0.06$	$0.8^{a} \pm 0.05$	0.359
Cooking loss (%)	$17.0^{a} \pm 1.01$	$16.5^{a} \pm 1.00$	0.730
L*	$36.04^{a} \pm 0.63$	$35.03^{a} \pm 0.62$	0.259
a*	$13.06^{a} \pm 0.27$	$13.17^{a} \pm 0.27$	0.782
b*	$10.67^{a} \pm 0.37$	$10.46^{a} \pm 0.37$	0.681
Tenderness (N)	$58.00^{a} \pm 4.43$	$61.78^{a} \pm 4.38$	0.548

[a,b] Row means with different superscripts differ significantly ($P \leq 0.05$)

The inclusion of the β-AA did not have any significant effect (P>0.05) on any of the physical parameters measured.

Table 6.8 Least square means (± s.e.) depicting the effect of the β-AA on the chemical parameters of *M. semitendinosus* of SAMM lambs

Chemical Parameters	**β-AA**		
	Absent	**Included**	**P-Value**
Dry matter (%)[#]	27.4 ± 0.43	26.0 ± 0.43	0.037
Protein (%)	$19.3^{a} \pm 0.34$	$19.1^{a} \pm 0.34$	0.565
Fat (%)[#]	5.5 ± 0.31	5.1 ± 0.30	0.323
Ash (%)	$1.1^{a} \pm 0.04$	$1.0^{a} \pm 0.04$	0.206

[a,b] Row means with different superscripts differ significantly ($P \leq 0.05$)

[#]Due to interactions main effects cannot be interpreted

Sustained juiciness, tenderness and atypical flavour were the only sensory parameters that were influenced by gender (Table 6.9). Neither the physical nor the chemical parameters were affected by gender (refer to Tables 6.10 and 6.11).

Table 6.9 Least square means (± s.e.) depicting the effect of gender on the sensory parameters of *M. semimembranosus* of SAMM lambs

Sensory Parameters	Gender		
	Ewe	Ram	P-Value
Lamb aroma intensity	77.4^{a} ± 0.64	77.5^{a} ± 0.64	0.952
Initial juiciness	75.3^{a} ± 0.88	74.5^{a} ± 0.88	0.383
Sustained juiciness	68.0^{a} ± 0.63	65.7^{b} ± 0.63	0.047
Tenderness	76.2^{a} ± 0.83	72.0^{b} ± 0.83	0.037
Mealiness	6.9^{a} ± 0.71	5.5^{a} ± 0.71	0.164
Residue	7.1^{a} ± 0.62	7.8^{a} ± 0.62	0.419
Overall lamb flavour$^{\#}$	79.1 ± 0.43	77.9 ± 0.43	0.064
Atypical flavour	0.9^{a} ± 0.39^{a}	2.6^{b} ± 0.39	0.005

^{a,b} Row means with different superscripts differ significantly (P ≤ 0.05)

$^{\#}$Due to interaction main effects cannot be interpreted

The meat from the ewes had a significantly higher sustained juiciness than that from the rams (Table 6.9). The sensory panellists also perceived the meat from the ewes to be more tender (76.23 ± 0.83) than that from the rams (72.03 ± 0.83). The ram meat (2.63 ± 0.39) had a significantly higher atypical flavour score than the meat from ewe lambs (0.92 ± 0.39). As pertaining to the physical parameters, gender had no significant effect (P>0.05) on any of these (Table 6.10).

Table 6.10 Least square means (± s.e.) depicting the effect of gender on the physical parameters of *M. longissimus dorsi* of SAMM lambs

Physical Parameters	Gender		
	Ewe	Ram	P-Value
Drip loss (%)	0.8^{a} ± 0.06	0.8^{a} ± 0.05	0.679
Cooking loss (%)	15.8^{a} ± 1.03	17.7^{a} ± 0.98	0.178
L*	35.31^{a} ± 0.64	35.76^{a} ± 0.61	0.613
a*	13.20^{a} ± 0.28	13.03^{a} ± 0.26	0.656
b*	10.78^{a} ± 0.38	10.34^{a} ± 0.36	0.399
Tenderness (N)	56.99^{a} ± 4.51	62.78^{a} ± 4.29	0.359

^{a,b} Row means with different superscripts differ significantly (P ≤ 0.05)

Table 6.11 Least square means (± s.e.) depicting the effect of gender on the chemical parameters of *M. semitendinosus* of SAMM lambs

Chemical Parameters	Gender		
	Ewe	Ram	P-Value
Dry matter (%)[#]	27.2 ± 0.44	26.2 ± 0.42	0.125
Protein (%)	19.1[a] ± 0.35	19.3[a] ± 0.33	0.811
Fat (%)[#]	5.7 ± 0.31	4.9 ±0.30	0.075
Ash (%)	1.1[a] ± 0.04	1.1[a] ± 0.04	0.763

[a,b] Row means with different superscripts differ significantly (P ≤ 0.05)

[#]Due to interaction main effects cannot be interpreted

Table 6.12 Least square means (± s.e.) depicting the interaction of β-AA and gender on overall lamb flavour

Parameters	β-AA	Gender	LSM ± SE
Overall lamb flavour	N	F	78.5[a,b] ± 0.61
	N	M	78.7[a] ± 0.61
	Y	F	79.7[a] ± 0.61
	Y	M	77.0[b] ± 0.61

[a,b] Column means with superscripts that differ, differ significantly (P ≤ 0.05)

The ram lambs that did not receive the β-AA in the diet had a significantly higher overall lamb flavour (78.7 ± 0.61) than the rams that did received (77.0 ± 0.61) the β-AA. On the other hand, the ewe lambs that received the β-AA had a significantly higher overall lamb flavour (79.7 ± 0.61) than the ram lambs that did received (77.0 ± 0.61) the β-AA.

Gender had no significant effect (P>0.05) on the ash and protein content of the meat. There were however interactions between the main effects for the following parameters: fat % and DM % (Table 6.13).

Table 6.13 Least square means (± s.e.) depicting the interaction of β-AA, gender and energy on measured parameters DM and fat

Gender	β-AA	Energy	LSM ± SE
		DM %	
F	N	H	$27.5^{a,b} \pm 0.96$
F	N	L	$28.9^{a} \pm 0.86$
F	Y	H	$27.0^{a,b} \pm 0.86$
F	Y	L	$25.3^{b} \pm 0.86$
M	N	H	$27.1^{a,b} \pm 0.86$
M	N	L	$25.9^{b} \pm 0.78$
M	Y	H	$25.2^{b} \pm 0.86$
M	Y	L	$26.6^{a,b} \pm 0.86$
		Fat %	
F	N	H	$5.5^{a,b} \pm 0.68$
F	N	L	$6.5^{a} \pm 0.61$
F	Y	H	$6.1^{a,b} \pm 0.61$
F	Y	L	$4.6^{b,c} \pm 0.61$
M	N	H	$5.4^{a,b} \pm 0.61$
M	N	L	$4.7^{b,c} \pm 0.55$
M	Y	H	$4.1^{c} \pm 0.61$
M	Y	L	$5.5^{a,b} \pm 0.61$

^{a,b} Column means with superscripts that differ, differ significantly ($P \leq 0.05$)

The ewes on the low energy diet that did not receive the β-AA (28.9 ± 0.86%) had meat with the highest DM % content. This group differed significantly from the other groups: the ewes on the low energy diet that received the β-AA (25.3 ± 0.86%), the rams on the low energy diet that did not receive the β-AA (26.0 ± 0.78%) and the rams on the high energy level that received the β-AA (25.2 ± 0.86%).

The ewes on the low energy diet that did not receive the β-AA (6.5 ± 0.61%) had the highest percentage fat in the meat. This group differed significantly from the following three groups: the ewes on the low energy diet that received the β-AA (4.6 ± 0.61%), the rams on the low energy diet that did not receive the β-AA (4.7 ± 0.55%) and the rams on the high energy diet that received the β-AA (4.1 ± 0.61%). There were also two other groups that differed significantly ($P<0.05$) from each other. These two groups were the ewes on the high energy diet that received the β-AA (6.1 ± 0.61%) and the rams on the high energy diet that received the β-AA (4.1 ± 0.61%).

6.4 DISCUSSION

The low dietary energy level lambs had a higher lamb aroma intensity, a result contradictory to the literature (Bas *et al*., 2000; Priolo *et al*., 2002). It is known that the amount of intramuscular fat present in the cooked meat affects both the juiciness and flavour (Bas *et al*., 2000). It has also been shown that an increase in the proportion of concentrate in the diet will lead to an increase in the intramuscular fat content of the lambs (Priolo *et al*., 2002). One would therefore expect that the lambs on the low energy diet would have less intramuscular fat and thus a lower aroma intensity due to the lower proportion of concentrate in the diet relative to the higher energy diet.

Sustained juiciness is the second sensation of juiciness and is determined by the slow release of serum and the secretion of saliva by the salivary glands, both of which are stimulated by fat (Bas *et al*., 2000). Avendano-Reyes *et al*. (2006) found an increase in the water holding capacity (WHC) of the meat of steers fed Zilpaterol hydrochloride (ZH); this in turns leads to meat that is perceived to be drier. It would therefore have been expected for the panellists to find the meat from the lambs that received the β-AA drier than that from the lambs that did not. The findings of this trial were in accordance with this. The panellists did perceive the meat from the lambs that did receive the β-AA (65.8 ± 0.63) as less juicy compared to the meat of the lambs that did not receive the β-AA (67.9 ± 0.63; Table 6.6).

As expected, the meat samples from the lambs that did not receive β-AA were more tender (as tested by the sensory panel (Table 6.6), although not significant there was also a tendency for the Shear force values (Table 6.7) to be higher for the lambs receiving the β-AA) than those from the lambs that received the β-AA. Avendano-Reyes *et al*. (2006) found that the increase in skeletal muscle resulting from feeding a β-AA is largely due to a hypertrophic increase in the fibre diameter, which unfortunately has the side effect of compromising meat tenderness. Both Hilton *et al*. (2009) and Leheska *et al*. (2009) also found that the use of ZH decreased the sensory tenderness and increased the shear force of the meat. Delmore *et al*. (2010) however concluded that although the use of ZH affects the tenderness of the meat it does not affect the consumer acceptance of the meat. In this experimental trial either the β-AA did not affect the tenderness of the meat or it was included in the diet at too low an inclusion level. Baker *et al*. (1984) found that the effect of a β-AA is more profound in more mature lambs.

Horcada *et al*. (1998) found that ewes had firmer subcutaneous fat and more intermuscular fat than rams. The presence of this fat in meat stimulates the salivary glands to secrete saliva, thereby producing the sensation of sustained juiciness. The higher sensation of sustained juiciness in meat from ewe lambs perceived by the sensory panel (Table 6.9) therefore aligns with expectations. The sensory panellists also perceived the meat from the ewes to be more tender. These findings are in accordance with Seideman *et al*. (1984); these researchers found that although ram lambs are ideal meat producing animals in terms of efficiency, they have less tender meat than ewes. While the meat of the ram lambs had a significantly higher atypical flavour score, Seideman *et al*. (1984) also found that the cooked meat from ram lambs was less tender and had more undesirable odours and flavours than that from wethers. This is in accordance with Crouse *et al*. (1978), who found that meat from heavy ram carcasses had a more intense aroma and flavour. The meat from older lambs would be less tender and have more intense flavour.

At the start of the trial it was expected that the animals that did not receive the β-AA would have meat with a higher fat content, with this being based on the results of studies such as that of Elam *et al*. (2009), who found that the use of a β-AA decreased the total carcass fat. This is consistent with the findings of this study. The ewe groups were also expected to have meat containing more fat as ewes deposit more total carcass fat than rams (Kirton *et al*., 1995). However it is surprising that the low energy diet ewes had meat with a higher percentage fat than the high energy diet ewe groups, even where both groups received the β-AA, the reason for this phenomenon is not clear and warrants further research.

6.5 CONCLUSIONS

The meat of the LE lambs had a higher sustained juiciness than the HE lambs. Therefore the lower the dietary energy in the diet the more juicy the meat is perceived by panellists.

The level at which the β-AA was included in the diet resulted in the meat being perceived as tougher and drier by the panellists. The ewe lambs that did not receive the β-AA on LE had the highest fat content while the ram lambs that did receive the β-AA on HE had the lowest fat content, therefore the fat content was decreased in the meat of the lambs that did received the β-AA.

As expected the meat from ewe lambs was found to be more tender than that from ram lambs. The difference in flavour between the genders was however unexpected as both ewes and lambs were slaughtered at the same age and both genders had received the same diets (low or high energy). Meat from ram lambs was found to have a significantly higher atypical flavour by the sensory panel than that from ewes. It is recommended that future studies test the effect of the inclusion level of the β-AA in order to determine at what point the fat content of the carcass starts to decline. The meat of ewes are more juicy and more tender than the meat of ram lambs, while the meat of ram lambs had a more tendency to an atypical flavour that is not associated with the typical overall lamb flavour.

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CHAPTER 7

GENERAL CONCLUSIONS

At the start of this trial it was expected that the animals that received the lowest dietary energy level would have a higher feed intake than those receiving the high dietary energy level and *vice versa*. In the case of the animals on the low energy level diet rumen fill is the primary factor determining the level of intake, whereas in the case of the high energy diet the amount of energy restricts intake before rumen fill occurs. It was also expected that the animals receiving the high dietary energy level would have a higher marbling fat percentage on the carcass relative to the animals consuming the low energy level diet.

When the trial was performed on an *ad libitum* feed intake basis (Experiment 2) it was observed that the lambs on the low dietary energy level indeed had a higher feed intake and subsequently a higher average daily gain (ADG) than the lambs on the two higher energy levels. An increase in the metabolisable energy content of the feed has previously been found to decrease the feed intake of lambs, providing the voluntary intake is not restricted by other factors such as rumen fill or gastrointestinal (GI) health. This will subsequently increase production efficiency by reducing the feed conversion ratio. The higher ADG of the lambs on the low plane of nutrition subsequently lead to both a higher slaughter and carcass weight, while in turn these lambs also had a higher yield in the commercial leg cut. Positive correlations for each energy treatment were observed between slaughter weight and the following parameters: carcass weight, leg yield, shoulder yield, neck yield, flank yield and the cranial (the fat thickness on the LD removed closest to the head of the carcass) fat thickness, as expected. No correlations were however found between the slaughter weight and the dressing percentage and caudal fat thickness.

The results anticipated regarding the β-adrenergic agonist (β-AA) were that the animals receiving the β-AA would have a lower feed intake, higher average daily gain (ADG), better feed conversion ratio (FCR), lower marbling percentage on the carcass (leaner carcass) and slightly tougher meat than those that did not receive the β-AA. On the completion of the trial it was however found that at the inclusion level used, the β-AA had no significant effect on the production or meat quality parameters and characteristics evaluated. Meat from the lambs receiving the β-AA was however perceived by the sensory panel to be drier and tougher than that from lambs that received feed containing no β-AA. Although the panellists perceived the meat as being tougher, no significant effect on tenderness as measured by the Warner-Bratzler shear force was noted. The fat content of the meat was not altered by addition of the β-AA; however it was observed in the interaction between the main effects (energy level and gender). Specifically, it was found that the ewes not receiving the β-AA had meat with a higher fat content and a higher visceral fat percentage in the carcass relative to their counterparts that received the β-AA. Taking the results from this trial into consideration, it is recommended that the inclusion of β-AA in the diet at a higher concentration in order to take advantage of its positive effects on production efficiency be evaluated further.

The effect of gender was expected. Overall it was found that when comparing the meat quality of lambs of different genders (ram, ewes and wethers), no significant differences are present between the meat of ewe and wether lambs. However, when comparing the meat of ram lambs with that of ewes; meat from ewes is of a better quality in terms of juiciness, tenderness and overall lamb flavour. Ageing of the lamb leads to the maturation of the tissues, bone, muscle followed by fat. Whereas the tenderness of the meat decrease as the age of the animal increases. Due to the young chronological age the lamb were slaughtered gender effects were not as profound as it would have been in older sheep since sexual maturity was not reached yet.

Therefore it is recommended to include the β-AA at higher inclusion levels in the diet for the commercial use of this specific β-AA in lamb production. Although it would be wise no to over supply this β-AA in the diet for it is a costly additive and to prevent too tough meat, since a negative compromise in the use of this β-AA is less tender meat.